INSIDE: Pullout star charts

TITAN: Earth of the outer solar system p. 34

November 2007

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The secret lives of black holes

A black hole's spin may power gamma-ray bursts, galactic jets, and other mysterious phenomena p. 28

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How to observe variable stars p. 56

Astronomers now measuring how fast black holes rotate are finding some that do so as fast as theory allows.

AND MORE!

The priest who anticipated the Big Bang p. 40

How galaxies are classified p. 54

Is LASIK good for observers? p. 74

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INSIDE: Pulsar starcharts
TITAN: Earth of the outer solar system p. 34
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How to observe variable stars p. 56
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Is LASIK good for observers? p. 74
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ASTRONOMY: ROEN KELLY

ON THE COVER

CENTER SECTION

34 Earth of the outer solar system

28 The secret lives of black holes

66 Who will save us from a killer asteroid?

56 How to observe variable stars

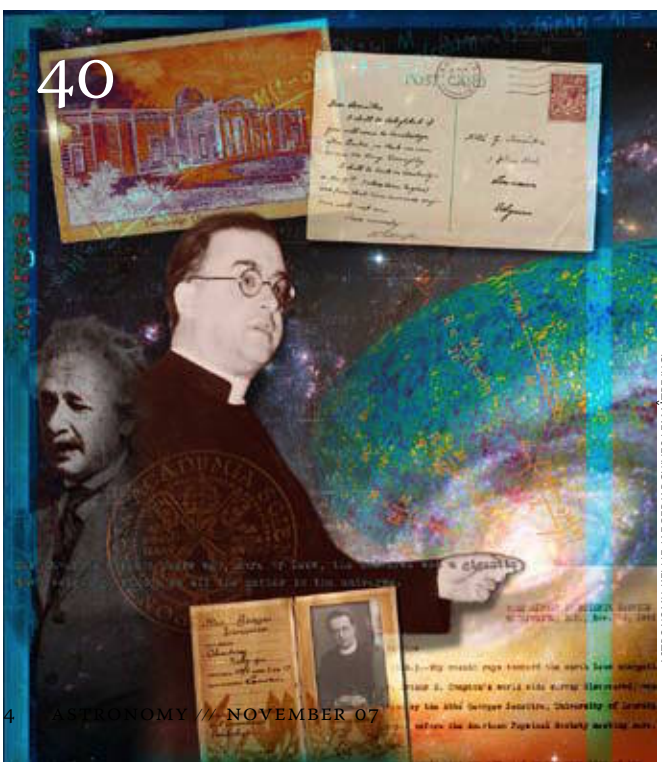
40 The priest, the universe, and the Big Bang

54 Illustrated: Making sense of galaxies

74 Is LASIK for you?

16 Dancing to a deaf wind

MICHAEL CARROLL FOR *ASTRONOMY*



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Astronomy

VOL. 35, NO. 11

The world's best-selling astronomy magazine

november 2007

06 **This month in *Astronomy***
Songs from black holes

08 **Letters**

10 **Bob Berman's strange universe**
Hall of mirrors

12 **Glenn Chaple's observing basics**
Spy a solar system wanderer

14 **Phil Harrington's binocular universe**
The sky's Triangle
ONLINE EXTRA: Explore a star cluster and a long-gone constellation.

16 **Stephen James O'Meara's secret sky**
Dancing to a deaf wind

20 **Astro news**
The Galaxy Zoo wants you, and more

28 COVER STORY

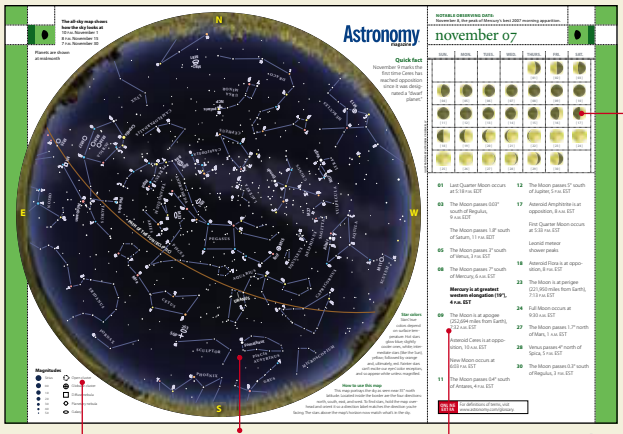
The secret lives of black holes
A black hole's spin may power gamma-ray bursts and galactic jets. But its rotation has been hard to measure — until now. **STEVE NADIS**
ONLINE EXTRA: Watch what happens to a black hole as it spins faster.

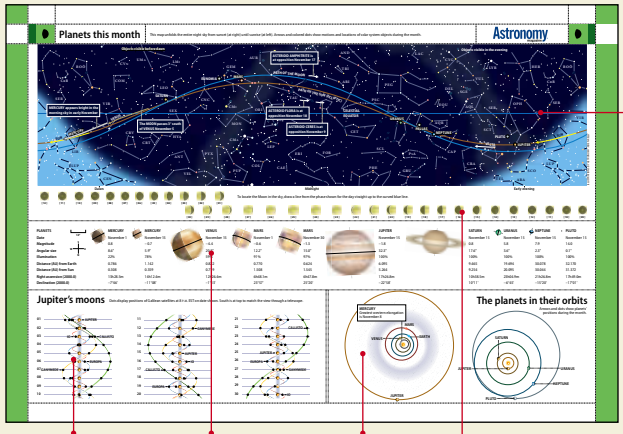
34 **Earth of the outer solar system**
Each Cassini flyby of Titan fills in the details of this frostbitten saturnian moon shaped by forces identical to those that sculpted Earth's surface. **MICHAEL CARROLL**
ONLINE EXTRA: How do Titan's landforms compare to Earth's?

40 **The priest, the universe, and the Big Bang**
A Belgian priest's extraordinary insights anticipated modern cosmology's most fundamental ideas. **YAËL NAZÉ**
ONLINE EXTRA: Georges Lemaître's big ideas included computers, too.

44 **The sky this month**
Mercury's great display before dawn
MARTIN RATCLIFFE AND ALISTER LING

EXCLUSIVE PULLOUT STAR CHARTS: Your guides for observing this month's night sky (p. 44)





54 **Illustrated: Making sense of galaxies**
Astronomers' efforts to explain galaxy types brought them from a tuning fork to a lemon.
FRANCIS REDDY; ILLUSTRATION BY KELLIE JAEGER

56 **How to observe variable stars**
If your observing list doesn't contain variable stars, here's an easy guide to some of the finest. **MICHAEL E. BAKICH**
ONLINE EXTRA: Explore eight additional types of variable stars.

62 **Ask Astro**

66 **Who will save us from a killer asteroid?**
Meet astronomers on the front lines of protecting Earth.
ROBERT REEVES
ONLINE EXTRA: Get the latest science on the Tunguska explosion.

70 **Astrolight reflectors offer quality optics**
Parks Optical's 6- and 8-inch Newtonian reflectors deliver top-notch optics at a reasonable price. **PHIL HARRINGTON**

74 **Is LASIK for you?**
Like any surgery, laser vision correction has pros and cons — especially for observers. **DANIEL PENDICK**
ONLINE EXTRA: Get tips on choosing an eye surgeon.

78 **New products**

80 **Coming events**

81 **Advertiser index**

86 **Reader gallery**

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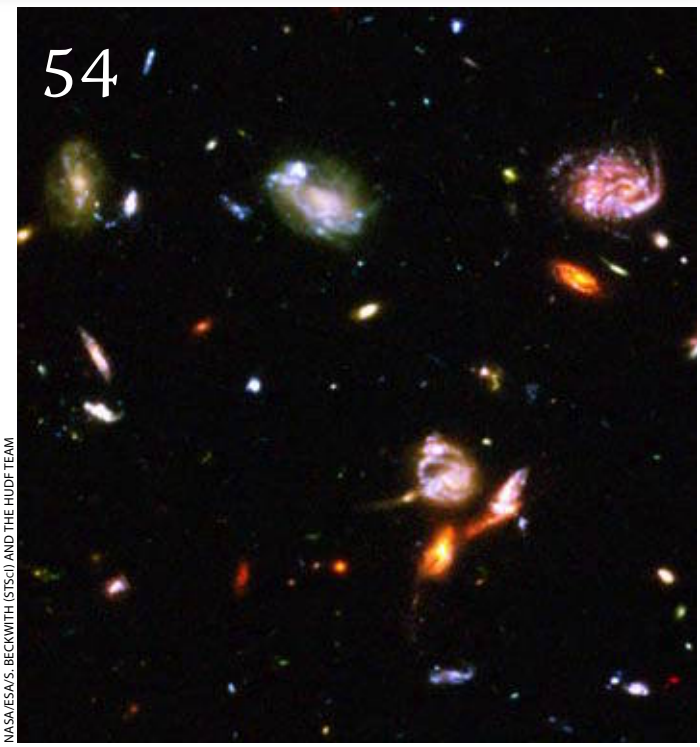

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SMITHSONIAN INSTITUTION

BY DAVID J. EICHER

Songs from black holes

Astronomers who study black holes are

cosmic magicians. They need to coax a great deal of meaning from precious little information. All we can tell about a black hole comes down to two things: mass and spin. How much a black hole weighs reveals a lot, but the relatively new science of deciphering black-hole spins promises to pay off even more. Contributing Editor Steve Nadis' story, "The secret lives of black holes" (p. 28), tells the inside story of this exciting area of research.

From afar, black holes appear to be simple, if energetic and dangerous, creatures. They consist of an event horizon — the point of no return, beyond which gravity is so intense that anything falling in, even light, will never escape. Typically surrounding the event horizon is a rapidly rotating disk, a whirling spiral of matter and energy. Much of the disk is destined to fall into the black hole, some flies outward into space. In some cases, the black hole itself spins — and in others, it doesn't.

Astronomers have only recently been able to measure black-hole spins. As Nadis describes, researchers Jeffrey McClintock and Ramesh Narayan of the Harvard-Smithsonian Center for Astrophysics have found that measuring the radius of a spinning black hole can yield its spin rate.

Other astronomers are listening to the black-hole hit parade. Some stellar-mass black holes emit high-frequency notes as they oscillate — according to some researchers, these black holes "sing." The oscillations can reveal how rapidly the black holes in question are spinning.

The payoff here is a clue to how black holes formed and evolved. "The spin retains a memory of these things," says Chris Reynolds, an astrophysicist at the University of Maryland. Spin also provides clues about longstanding mysteries like what powers jets associated with black holes. "The question, long debated," says Roger Blandford of Stanford, "is whether the power behind jets and other phenomena derives from the black hole or the accretion disk." Other payoffs include running some of the most accurate tests of general relativity to date.

The field is suddenly a big and active one, and it makes for riveting reading.

I also encourage you to check out Michael Carroll's "Earth of the outer solar system" (p. 34). Carroll, a well-known astronomical artist and journalist, is a longtime contributor to *Astronomy*.

Carroll's latest story provides the most up-to-date look at the Cassini spacecraft's revolutionary unveiling of Saturn's moon Titan. This methane-soaked world, so earthlike in its character and early history, is one of the most curious places in the solar system.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 35, Number 11

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*The camera was a Canon 5D Digital SLR with a full 35 mm sensor. All of the above comparisons were taken using the original full frame images without any processing. The above images of M44 were taken by Jack Newton. See for yourself by downloading the two images and viewing them at 100% screen resolution from Meade.com.
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Place your bets

I recently read Stephen James O'Meara's column in the July 2007 issue. I found his information about M20 and M21 very interesting. After I read the article, I found something even more interesting: His article appears on pages 20 and 21. If this was intentional, there are some very clever people on staff at *Astronomy*. If it was coincidental, I think the odds are, well, astronomical. **— TONY IANNONE,** FT. LAUDERDALE, FLORIDA

This lucky position results from a timely subject and a coincidental placement. If we did take credit for the M20–M21 placement, the Astronomy *staff would die from exhaustion trying to produce a magazine if O'Meara ever wrote about double open cluster NGC 869 and NGC 884.* **— JEREMY McGOVERN,** ASSISTANT EDITOR

A beautiful universe

The Hubble photograph of M101 ("Beautiful universe," August 2007) was fantastic, and the caption reminded me of the long time it took for the light to reach us (25 million years).

But what I find really stunning about such images is that, after focusing on the main subject, you can see other galaxies obviously so much farther away. **— COLIN HENDERSON,** CHELTENHAM, ENGLAND

In our backyard

The June 2007 article "The first new world" was a great look at history and how Uranus was almost discovered several times before. I wonder what we would be calling it if it had been.

THE TRIFID NEBULA (M20) in Sagittarius is a popular observing target. REU PROGRAM/NOAO/AURA/NSF

I also enjoyed "Saturn's sweet surprises" and the two-page "Anatomy of a ringed planet" that followed it.

With all the excitement and wonder about extrasolar planets, which are very exciting, it's also nice to explore our own celestial backyard now and then. **— ED SULESKY,** FRIDLEY, MINNESOTA

Black holes in a strange universe

In my December 2001 column, and then again in my May 2004 article "Frames of Reference," I stated unequivocally that black holes cannot fully form, and, indeed, never quite form as viewed from our perspective, our reality. In the former, I even said the only black holes that could exist must have formed at the beginning of the universe. None can possibly materialize today because they require infinite time to fully do so.

Physicists at Case Western Reserve University announced in June new findings that black holes formed only in the universe's first moments and that information piles up on the event horizon, instead of being lost forever.

If this holds up, it means *Astronomy* was apparently the first to have published these iconoclastic concepts, years in advance. This really is a strange universe, and you can count on us to bring you the newest dirt from the most bizarre alleyways of space-time. **— BOB BERMAN**

Clarification

Two competing dates were given in "Lighthouse of the skies" (August 2007). The USNO was at the Capitol Hill site from 1830–1844. It was at Foggy Bottom from 1844–1893. **— *ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Online poll results

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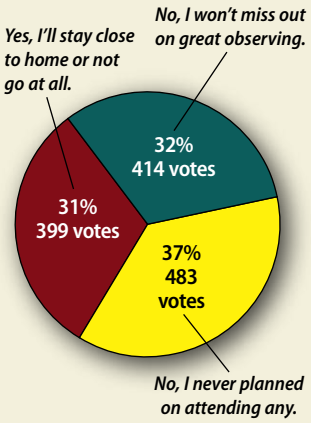
Yes, I'll stay close to home or not go at all.
No, I won't miss out on great observing.
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31% 399 votes
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BY BOB BERMAN

Hall of mirrors

Astronomy leads us to deep issues.

Many are so profound, we can't even handle them. Take the question of intelligence lurking throughout the cosmos. This topic arises when we look for life beneath the martian surface or perform SETI searches. We assume life is out there, but we don't know its limits. Some think Earth's biosphere is a single interconnected organism named Gaia. Might that be true elsewhere? Could Jupiter be an unrecognized life-form?

Or consider nature itself, which most of us feel is smart. Yet, it supposedly arose randomly from inert matter. So we have this universe, which is basically as dumb as gravel. A few billion years ago, some witless bits of carbon, oxygen, and hydrogen slammed together for awhile until out popped Kobayashi — the Japanese competitive eater who devours hot dogs. How carbon and oxygen atoms should have ever developed a taste for frankfurters is mysterious. But there you have it, and it probably happened on other worlds, too. We're left with a combo plate: Some of the universe is smart, some of it is dumb. We're never quite sure where to draw the line.

Equally weird are space and time. Space is a strange and unique item — you can't take it to a lab and analyze it like beef jerky. It's like a container without walls. Space seethes with an enormous enigmatic energy, and, each second, trillions of cubic light-years more of it materializes from nothingness. Nobody knows why or how it does that.

Time is just as odd. We've talked in the past about its iffy nature, and whether it actually exists outside of the human mind. Theorists say there was no time before the Big Bang, which is why we're not supposed to ask what things were like the Saturday night before the non-cosmos went kaplooie.

Then you've got the biggest troublemaker: consciousness. Former *Encyclopaedia Britannica* publisher Paul Hoffman considers it science's deepest unsolved issue. We observe objects and think about them, but such processes occur strictly in our consciousness, which introduces biases of all sorts. How does it influence what we see and believe? We are unaware because no one knows what consciousness is or how it could have arisen. We're forced to ignore it, even if we're likely overlooking a key component that would help clarify the universe.

WE'RE LEFT WITH a combo plate: Some of the universe is smart, some of it is dumb.

Quantum theory shows that consciousness influences the outcome of experiments. The behavior of small objects depends on whether anyone's watching. This is fact, but how far does it go? All the way to the edges of space-time? Experiments are now underway to determine how deep into the macroscopic realm these observer-determined effects reach. One possible consequence is that the universe may exist only because we do. This sort of thing was first argued by George Berkeley, for whom the town and campus were named. He eloquently demonstrated what we perceive are our perceptions — and only assumed the cause of those perceptions to be an independent, external world. The universe may indeed be correlative with us.

We can't even take the Moon for granted. Earth's satellite looks the way it does because sunlight bounces off of it. But these photons are just bits of magnetism and electricity. They have no visual properties, no appearance or form, until they interact with a complex retina-brain system after transferring their energy. What could the Moon possibly look like if our minds didn't process photons in unique ways? When nobody's watching, the Moon certainly doesn't remotely resemble the thing we remember. It's even possible the Moon isn't there at all when everyone's asleep. Its component energy-particle waves exist as quantum probabilities that apparently take form only when their wave functions collapse, which happens whenever it's observed.

If all this sounds far-out, well, you bet it is — although no more so than the standard model where the universe popped out of nothingness like a jack-in-the-box. Any way you slice it, the biggest aspects of the cosmos are strange and mysterious.

Religions push back these mysteries by one step, and science, understandably, finds this unhelpful, even if it cannot come to the rescue itself. We're left with the stuff no one talks about, the uncle with the facial tic that everyone tries to ignore.

I think mysteries are among the best parts of astronomy, the perfect accompaniments to a starry night. Scientists love 'em too, as they brilliantly chip away. It would be nice, however, if cosmologists would put a lid on their arrogant ghetto-talk about their latest theory of everything and admit — just once in a while — that their knowledge is a single snowflake in the blizzard of the unknown.

Me, I'm gonna observe the Moon. Want a hot dog?

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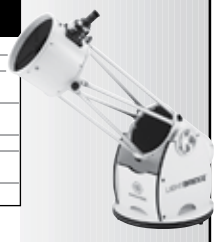

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BY GLENN CHAPLE

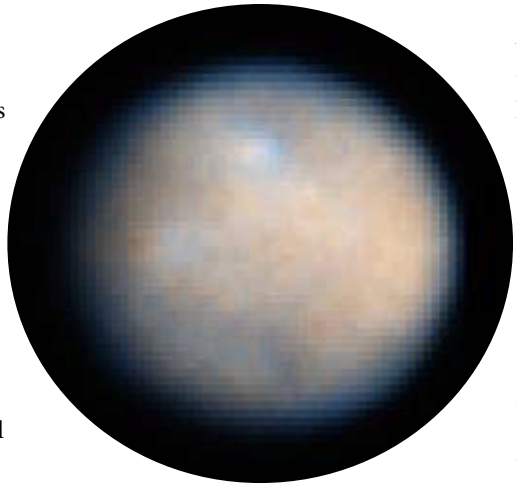
Spy a solar system wanderer

Someone recently gave me a bumper sticker that reads "Honk if Pluto is a Planet." The message conveys the controversy from the International Astronomical Union's (IAU) decision to demote Pluto to "dwarf planet" status. But before Pluto lost its planetary stripes, there was Ceres.

Italian astronomer Giuseppe Piazzi discovered Ceres January 1, 1801. Orbital calculations placed Ceres some 257 million miles (2.8 AU) from the Sun, between Mars and Jupiter. At first, astronomers thought Ceres might be the "missing planet" long believed to exist in the vast expanse that separates those two planets.

There was one problem: At magnitude 7.2, Ceres couldn't be very large. In fact, the would-be planet proved to be smaller than our Moon — modern-day measurements put its diameter at around 590 miles (950 kilometers). The death knell to Ceres' status as a planet came with the discoveries of three more "planets" in the Mars-Jupiter gap: Pallas in 1802, Juno in 1804, and Vesta in 1807. Not only was Ceres puny by planetary standards — it wasn't even unique. By the mid-1800s, as astronomers discovered more of these bodies, they demoted Ceres to the rank of "minor planet." There it remained until last year's IAU redefinition.

We now refer to Ceres and its fellow wanderers as "asteroids." Greek for "star-like," it's a term coined by Sir William Herschel in 1802. Purists may consider the expression to be unscientific — asteroids are anything but stars — but it aptly describes Ceres' appearance in backyard telescopes. Only by its night-to-night movement can you discern an asteroid from the background stars.



ASTEROID CERES has a round shape like Earth and may have a thin, dusty outer crust and rocky inner core. The Hubble Space Telescope captured this view of the asteroid during December 2003 and January 2004. NASA/ESA/J. PARKER (SwRI)/P. THOMAS (CORNELL UNIVERSITY)/L. McFADDEN (UNIVERSITY OF MARYLAND)/M. MUTCHLER AND Z. LEVAY (STScI)

Instead of joining the planetary debate, let's go outside and experience Ceres with our own eyes. A favorable opportunity occurs during the first 3 weeks of November, especially around the 11th, when Ceres arrives at opposition some 4° north and slightly east of the 3rd-magnitude star Alpha (α) Ceti (see the finder chart in "The sky this month" on page 51). Ceres is visible through binoculars and small telescopes.

To capture Ceres, carefully scan the location indicated on the finder chart for the date you're observing. If you're working with a telescope, use low power. When you spot a suspect in the predicted area, make a sketch that includes the suspect and surrounding field stars. If you are new to sketching the sky, be sure to watch *Astronomy* Editor David Eicher's how-to video at www.astronomy.com/videos. Pay attention to the area where Ceres will be a night or 2 later. At that time, repeat your observation. If your suspect has moved to this new location, congratulations — you've found Ceres! Continue your Ceres watch until a gibbous Moon invades this part of the sky November 22.

Asteroid observing is an enjoyable pastime that doesn't require a large telescope or expensive equipment. I glimpsed my first asteroid, Vesta, back in 1971, using a small handheld 8x refractor — even though my unaided eyes would have sufficed. In subsequent years, I tracked down more than 100 asteroids as faint as 11th magnitude using a 3-inch reflector.

Information on the oppositions of easily observed asteroids appears regularly in *Astronomy*. For an annual list of favorable oppositions of bright asteroids, refer to the Minor Planet Center web site at cfa-www.harvard.edu/iau/mpc.html. You'll find more information on asteroid observing by logging on to the Lowell Observatory Asteroid Resource page at asteroid.lowell.edu or the Astronomical League's Asteroid Club site at www.astroleague.org/al/obsclubs/asteroid/astrcobs.html.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com.

Next month: Learn the ABCs of eyepieces. Clear skies!

What *Really* Is the Universe Made of? Welcome to the Dark Side

Tackle this intriguing cosmic question with a theoretical physicist at the California Institute of Technology

There's more to the universe than meets the eye—a lot more. In recent years scientists have discovered that 95 percent of the contents of the cosmos is invisible to all of our current methods of direct detection. Yet something is definitely there, holding galaxies and galaxy clusters together, and governing the shape and fate of the universe.

Scientists call these invisible components dark matter and dark energy—"dark" because these phenomena don't emit light, not because we aren't learning more and more about them. Indeed, dark matter and dark energy are the most eagerly studied subjects in astronomy and particle physics today. And for good reason—what could be more exciting than cracking the mystery of the fundamental constituents and overall composition of the universe?

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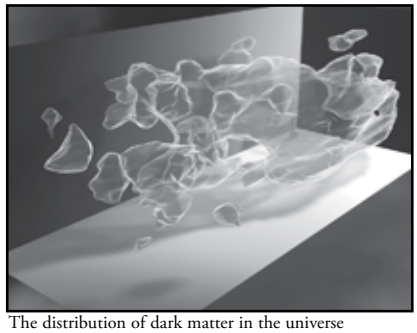

NASA, ESA and R. Massey (California Institute of Technology).

The distribution of dark matter in the universe

About Your Professor

Professor Sean Carroll is a Senior Research Associate in Physics at the California Institute of Technology. He received his Ph.D. in Astrophysics from Harvard, did postdoctoral research at MIT and UC Santa Barbara, and taught at the University of Chicago. He has received research grants from NASA, the U.S. Department of Energy, and the National Science Foundation. In 2006 he was awarded the Arts and Sciences Alumni Medallion from Villanova University.

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BY PHIL HARRINGTON

The sky's Triangle

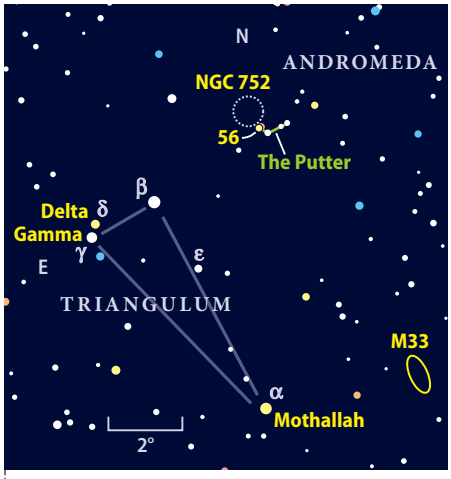
Have you ever actually tried to see the constellations? I don't mean their stick-figure patterns; I mean their actual namesakes. In most cases, it's nearly impossible. Cassiopeia is easy to see as a W, but not as a queen sitting on a throne. And imagining Pegasus as a giant square is straightforward enough, but a flying horse? Not very likely.

But of all the constellations in tonight's sky, one definitely looks like its name. The three primary stars in Triangulum unquestionably form a triangle. Although Triangulum's stars are on the faint side, they are fun to study through binoculars and hold the key to a few of autumn's hidden treasures.

Let's begin at the apex star, **Mothallah**, or Alpha (α) Trianguli. Alpha is a great starting point for finding the **Pinwheel Galaxy** (M33). Center Alpha in your binoculars, and then look for a faint star about half a field of view to the west. Center on this star, and then look for a faint glow near the western edge of the field. That's M33.

What's that? You don't see it? I'm not surprised. At 3 million light-years away, it's the second-closest major galaxy to our own, but M33 can be far more difficult to find than others much farther away. The problem is its low surface brightness. When observers talk about surface brightness, they refer to the level of contrast an object has against the background sky. M33's contrast is so low, you might pass over it the first time without even noticing it. But with patience, you'll spot it.

Okay, now shift over to **Gamma (γ) Trianguli** in the triangle's southeastern corner. A glance through binoculars reveals Gamma is the brightest member of a triple star. Or at least, it looks that way. The other two stars, 7 Trianguli to the south and **Delta (δ) Trianguli** to the north, only lie along the same line of sight. Even



CROSS TRIANGULUM'S border into the constellation Andromeda to find an asterism amateur astronomer John Davis views as a golf putter. *ASTRONOMY:* ROEN KELLY

though they are nowhere near each other in space, they create a pretty illusion through binoculars.

I'm sure you have heard our Sun, a yellow-dwarf star, referred to as an "average" star. But have you ever counted how many yellow-dwarf stars are in our sky? Not that many. But Delta Trianguli is one. In fact, Delta is a binary star made up of two yellow dwarfs that lie so close together, astronomers can resolve them only using special interferometry techniques. According to James Kaler, professor emeritus of astronomy at the University of Illinois, the system's larger star has a mass equal to our Sun, while the other is about 0.8 solar-mass. This makes the Delta system a science-fiction fan's nirvana. As Kaler says on his web site (www.astro.uiuc.edu/~kaler), the inhabitants on a hypothetical planet "would see two yellow suns looping around each other" in the sky. The double sunset that Luke Skywalker witnessed on Tatooine in *Star Wars: A New Hope* could be a reality there!

To find our final two targets this month, head northwest from Delta to Beta (β) Trianguli, and continue across the invisible border into Andromeda. About a binocular field beyond Beta, you'll bump into a slim triangle of stars. The brightest star of the three, known as **56 Andromedae**, is also a yellow star like our Sun, but much bigger: a yellow giant. The second-brightest point in the triangle is a cooler, orange giant star. Defocus your binoculars slightly to boost their colors.

John Davis, a veteran binocular observer from Amherst, Massachusetts, sees a golf putter when he looks here. He suggests the triangle itself marks the head of the putter, while a line of four other suns tilting northward makes up the club's shaft. Because of the stark surroundings, the putter asterism stands out nicely.

You'll even find a "golf ball" just east of Davis' putter. That's actually the open cluster **NGC 752**. Look for a round, grayish smudge measuring about as large as a Full Moon. While most binoculars resolve only the group's brightest sun, a 9th-magnitude orb just south of the cluster's center, 70mm and larger binoculars add several fainter points strung across the core.

After your observing session, e-mail me at phil@philharrington.net and let me know how you made out spotting these targets.

Next month, we have a date with some sisters. Until then, remember that two eyes are better than one.

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BY STEPHEN JAMES O'MEARA

Dancing to a deaf wind

It happened in a flash. On the morning of November 17, 2006, I was scanning the predawn sky for Leonid meteors when a magnificent magnitude –4 bolide charged from the zenith. It terminated about 20° above the eastern horizon in an unusually bright explosion of white

light. Sparks flew in all directions from that final burst before the meteor vanished.

I expected to hear a delayed crack or boom following the meteor's explosion, but the air remained still and undisturbed. Still, the spectacle carried enough intensity to make me flinch. Seeing this fireball meet its fate without a whisper reminded me of the words of Ohiyesa, the Native American physician and reformer, who said that each soul that dies must meet the Great Silence alone.

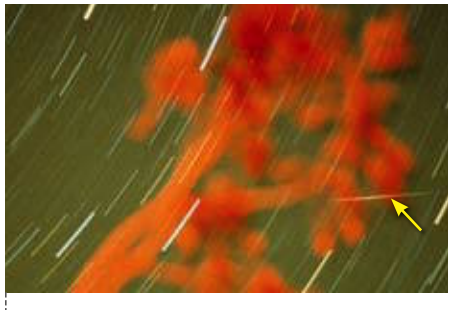
A ballet of light

But the spectacle was not over — I viewed the flash's ghost: a luminous cloud left behind in the meteor's wake. Straight and sharp, the phantom lanced the stars above the tree line, where it remained. Suddenly, the train buckled like a boxer who received a kidney punch. Over the next few minutes, it faded to black and disappeared.

Still the show was not over, because the ghostly glow remained visible through 10x50 binoculars. Spellbound, I watched the delicate waif of light sway to the silent rhythms of upper-atmospheric winds. Over the next half hour, the train changed shape dramatically 7 times before it once again faded from view.

It was a celestial "dance of the seven veils." That phrase is rooted in an ancient myth about Inanna, the richly dressed Sumerian goddess of love and war, who descended into the underworld — the realm of death — to claim its ruling from her sister Ereshkigal. Along the way, Inanna "degenerated," being forced to surrender a piece of her jewelry or clothing at each of the realm's seven gates — until she stood before her sister stripped of her worldly possessions. Unfazed, the sister sentenced Inanna to death. The tale is a metaphor for the blossoming of life and its ultimate decay. It illustrates how a robust object diminishes by degrees until the end. Like the meteor and its train, life is a transformation by descent.

As my sketches below show, after the train buckled, it broke into pronounced "beads." Minutes later, the train transformed into a "diamond-studded ring" with a thin, beaded wisp rising from it like a comet's tail. The ring then metamorphosed into a diffuse butterfly. Meanwhile, a sharp ray of light formed parallel to, and south of, the upper end of the beaded wisp. About 5 minutes later, the train looked like a binocular comet, sporting a glorious head and tapered tail; careful scru-



A LEONID METEOR (arrow) streaked across the sky in November 1999. The photographer illuminated a tree branch with a red light, creating an illusion of bright celestial bodies in the foreground. DON SCHECHTER

A flash dancing on its grave

THESE SKETCHES overlaid on sky images recreate the meteor train O'Meara observed the morning of November 17, 2006, from Hawaii. The view isn't exact — this isn't the actual field or the accurate apparent drift. STEPHEN JAMES O'MEARA

tiny, though, showed a small, beaded hook appended to the "comet's" head.

Finally, what started out as a sharp vertical streak in the sky appeared as two phantom trains running parallel to the horizon. Over time, the more easterly (lower) of the two trains diffused into invisibility. After another half hour, the final phantom faded.

Persistent trains

When meteor trains last for more than 10 seconds or so, they are called "persistent meteor trains." Persistent trains mostly originate from fast meteors, such as those from the Leonid and Perseid showers. In recent years, observers found other meteor showers, such as the slower Geminids, also show persistent trains, but those trains are much fainter. To see such persistent trains, one only has to point a telescope at the path of a bright meteor, according to astronomer Peter Jenniskens of the SETI Institute. Persistent trains can last for many minutes, changing shape in the strong upper-atmospheric winds.

As the meteoroid descends, its atoms collide with surrounding air molecules, creating a glowing cylinder of hot ionized gas, which we see as the meteor train. When the gas cools, the meteor's light quickly disappears. Some oxygen lines tend to glow longer and cause a green wake. After the wake fades, the glow of the persistent train becomes gradually more intense, with an eerie orange color. Jenniskens and colleague John Plane of the University of East Anglia have discovered the cause of that orange glow: the reaction of meteoric iron atoms with ambient ozone. The ozone diffuses into the train, and the reaction creates iron oxide (FeO) in an excited state.

THIS TRAIN from a Leonid bolide materialized along the constellation Hydra's body. The Leonid shower provides observers terrific opportunities for seeing trains. FRANK ZULLO

As time passes, the train drifts and becomes progressively deformed by high-altitude winds. Observations of a single train evolving into two parallel ones — like the one I witnessed — have been made for more than a century. In a 1908 issue of *The Observatory*, C. C. Trowbridge writes, "Many trains have been recorded as appearing like a double line of light, which is explained on the assumption that the luminosity is greatest near the outside of the train, the train thus being tubular."

In a 2005 *Journal of Geophysical Research* abstract, John Zinn and Jack Drummond of the Los Alamos National Laboratory successfully modeled the meteor train as a hot cylinder that first expands radially and then rises because of buoyancy. As it rises, the cylinder evolves into a pair of counter-rotating linear vortices. "These line vortex phenomena are offered as an explanation for the otherwise mysterious parallel pairs of trails that are often observed," the authors explain. Still, the mechanism is not well understood, and the need for detailed observations of the train phenomenon continues. I would like to hear your reports of any meteor trains you've witness. Also, keep your eyes focused skyward for any Leonid bursts this November. As always, e-mail your observations to me at someara@interpac.net.

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One triplet competitor costs $700 more than the AT90EDT and was quoted as taking 60 to 180 days to deliver when this ad was written. It has a one-year warranty, and a carrying case is an extra-cost option.

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In addition, a lockable hard case is standard equipment with the Astro-Tech – not an extra-cost option as it is with the higher-priced competitor. The case interior is die-cut to hold a 1.25" or 2" star diagonal and up to five eyepieces, as well as your AT90EDT.

Does the competition stack up with the AT90EDT? Doesn't sound like it.

The fully multi-coated AT90EDT triplet optics use all premium Ohara glass, including an FPL-53 element, for virtually zero chromatic aberration.

Of course you get the features Astro-Tech is known for – rotating dual-speed 2.7" rack-and-pinion focuser; retractable dew shield; 1.25" and 2" brass compression ring eyepiece holders, etc.

There are six Astro-Tech refractors, starting with the $349 AT66ED that *Astronomy* magazine said "everyone should own." Each uses ED glass for sharp, high contrast images free from spurious color. Each is a superb first telescope and a great second scope for travel and backyard astronomy. Each could well be the last and best telescope you will ever own.

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from **Astronomy Technologies**

Astro-Tech is available at these U. S. dealer websites:
astronomics.com • highpointscientific.com
blueplanetoptics.com • auroraastro.com

In Europe, Astro-Tech is available at these websites:
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Dealer inquiries: info@astronomytechnologies.com

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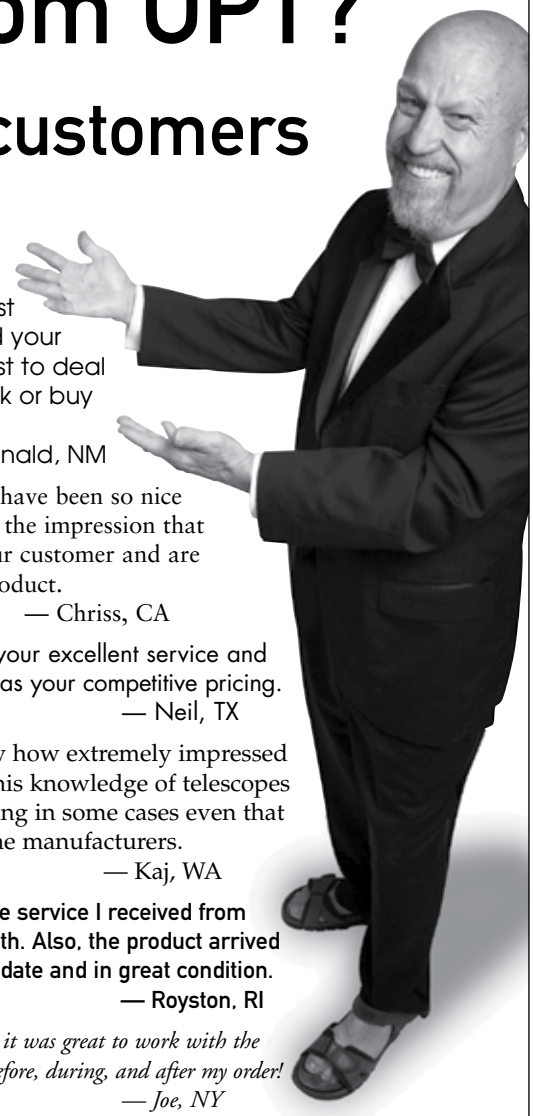

Craig Weatherwax, Founder of OPT.

Your web site is the best out there and you and your employees are the best to deal with. I would never look or buy from anybody else.
— Donald, NM

All of your sales persons have been so nice and helpful. You give me the impression that you really care about your customer and are passionate about your product.
— Chriss, CA

May I just thank you for your excellent service and attention to detail as well as your competitive pricing.
— Neil, TX

I wanted to let you know how extremely impressed I was with the depth of his knowledge of telescopes and accessories, surpassing in some cases even that of technical support at the manufacturers.
— Kaj, WA

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— Royston, RI

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Introducing the SkyScout from Celestron: The SkyScout is a revolutionary, one of a kind, patented handheld device that instantly identifies and/or locates any celestial object visible to the naked eye, providing educational and entertaining information, both in text and audio.

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Item Includes: Carry Case, Earphones, Hand Strap, USB Cable

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Naked Sun NASA's Solar and Heliospheric Observatory (SOHO) reported seeing no sunspots July 24. Their absence likely indicates the Sun has reached solar minimum.

For the latest news on space discoveries, spacecraft missions, and sky events, visit **Astronomy.com/news**

Astronews

SDSS

BIG RED. M87 is a massive elliptical galaxy at the heart of the Virgo galaxy cluster. Computers can't distinguish between elliptical and spiral galaxies as well as people can. Web-based Galaxy Zoo hopes volunteers will help sort out a million galaxies in the Sloan Digital Sky Survey.

22 50th anniversary of first microbes in orbit

24 Quadruple star system may host planet

26 Spinning Altair imaged

26 Early universe was more active

The Galaxy Zoo wants you

A new web-based project called Galaxy Zoo (www.galaxyzoo.org) is calling on the public to help classify a million galaxies imaged as part of the Sloan Digital Sky Survey. This will help scientists better understand how the cosmos evolved.

After viewing a 3-minute online tutorial, Galaxy Zoo presents team members with galaxy images. Participants must decide whether each image shows a spiral or an elliptical galaxy and, if a spiral, decide which way the galaxy seems to be rotating.

"The human brain is actually better than a computer at pattern-recognition tasks like this. Whether you spend 5 minutes, 15 minutes, or 5 hours using the site, your contribution will be invaluable," says Kevin Schawinski of Oxford University, one of Galaxy Zoo's creators.

Schawinski says projects like NASA's Stardust@home, which invites the public to identify interstellar dust grains the Stardust spacecraft returned, provided Galaxy Zoo's inspiration.

"Non-professionals have always been deeply involved in studying the sky, and they now have yet another opportunity to make themselves really useful," says Sir Patrick Moore, a Galaxy Zoo supporter and the world's best-known amateur astronomer. Organizers hope some 30,000 people will take part.

— FRANCIS REDDY

MARK JIRSA/MINNESOTA GEOLOGICAL SURVEY

FALLEN ROCK. Fragments shot out of an ancient impact in Ontario lie exposed on the surface in northeastern Minnesota. Tsunamis resulting from the strike mixed seabed rocks with falling ejecta.

Forest fire unveils ancient ejecta

Geologists say an outcrop of dark, concrete-like rock in northeastern Minnesota came from Ontario's Sudbury structure, Earth's second-largest and fourth-oldest impact crater. The 160-mile-wide (257 kilometers) crater lies some 450 miles (725 km) away.

Mark Jirsa of the Minnesota Geological Survey found the outcrop when a wildfire forced him to explore new areas along the state's Gunflint Trail. When the impact struck 1.85 billion years ago, the region was probably part of a shallow sea, he says.

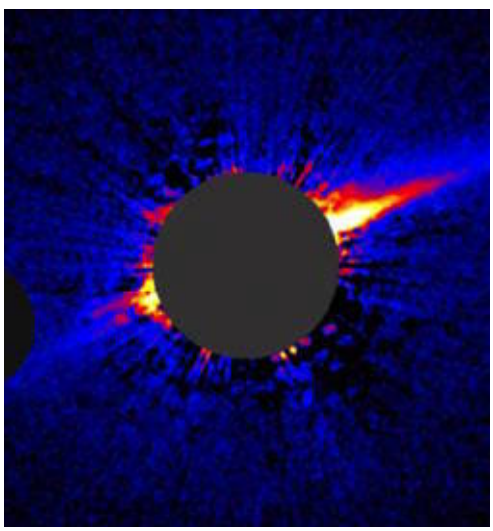
The new samples suggest a huge tsunami may have ripped up the shore and mixed seafloor material with rocks falling from the sky. The impacting comet or asteroid exploded with the force of several billion Hiroshima-sized nuclear bombs. **— F. R.**

Needle-shaped disk discovered

Astronomers have detected an elliptical, needle-shaped debris disk surrounding the young star HD 15115. Their paper appeared in the May issue of *The Astrophysical Journal Letters*.

Paul Kalas, James Graham, and Michael P. Fitzgerald — all from the University of California at Berkeley — made the discovery using NASA's Hubble Space Telescope and the W. M. Keck Observatory in Hawaii.

"The lopsided disk presents a host of new challenges for theorists," says Kalas. The biggest challenge is finding out what causes this odd disk's elongated shape. The astronomers theorize another star, HIP 12545, that lies about 10 light-years away from HD 15115 causes planetary upheaval within the needle-shaped disk, resulting in its long, asymmetric shape. **— LAURA LAYTON**



NASA/ESA/P. KALAS (UNIV. OF CALIFORNIA, BERKELEY)

ASYMMETRIC DISK. This lopsided debris disk surrounds the star HD 15115 in the constellation Pictor. The disk is seen edge-on and appears thicker in the upper right than in the lower left of this image.

QUICK TAKES

BIG SCOPE, BIG MONEY
The Gordon and Betty Moore Foundation has donated $15 million to the Thirty-Meter Telescope (TMT) project .

ISS HOME IMPROVEMENT
NASA has bought a $19 million Russian-built toilet system for the International Space Station.

CASSINI 5, SATURN 60
NASA's Cassini spacecraft has found its fifth satellite. Known as S/2007 S4, the 1.2-mile (2 km) lump of ice and rock is Saturn's 60th moon.

O-RINGS AGAIN
NASA is studying why recent batches of O-ring seals for shuttle solid rocket boosters contain more salt-grain-sized specks of unmixed rubber than previous batches.

OFF TO MARS
NASA's Phoenix Mars Lander launched from Cape Canaveral in Florida August 4, bound for the Red Planet.

PRICING EXOMARS
In July, the European Space Agency (ESA) moved one step closer to landing its ExoMars rover on the Red Planet in 2013. ESA asked the French-Italian company Thales Alenia Space to price the rover's design and construction.

NO BLING
Uranus and Neptune would need 7 times more carbon to form diamonds in their interiors, says a University of Amsterdam team.

MAKE THAT 4
The discovery of 2007 NS2 gives Mars its fourth so-called Trojan asteroid. These bodies lag or lead Mars by 60° in its orbit around the Sun.

NO SHOT GLASS
A NASA review board found no validity to charges astronauts were drunk before flying.

NEW SPACESUIT
MIT professor Dava Newman has designed a body-hugging spacesuit prototype made of spandex and nylon.

GEMINI OBSERVATORY

ICE MACHINE. **Possible water-ammonia geysers on Pluto's moon Charon (lower right), illustrated here, may replenish surface ices.**

Does Pluto's big moon host volcanoes?

New observations using the Gemini North Telescope in Hawaii suggest water-ammonia volcanoes erupt on Pluto's largest moon, Charon. Jason Cook at the Southwest Research Institute in Boulder, Colorado, led a team that found patches of crystalline water ice and water-ammonia mixtures (ammonia hydrates) on the moon's surface.

Neither type of ice can survive long on an airless world. Over time, cosmic rays and solar ultraviolet light gradually destroy their structures. "Some mechanism is renewing Charon's surface, and cryovolcanism is the most probable of the possible mechanisms," the team reported in the July 10 issue of *The Astrophysical Journal*.

Ammonia hydrates can keep water liquid down to –142° Fahrenheit (–97° Celsius). Subsurface liquids may rise through fissures and vent as geysers, much as they do on Saturn's moon Enceladus. Liquids in the plume quickly freeze and fall to the surface as snow, which creates the fresh ice patches the team observed.

But if Charon can do this, says Cook, so can other large Kuiper Belt objects. If ammonia hydrates are common in the Kuiper Belt, the astronomers suggest this frigid region may hold more liquid water than Earth. **— F. R.**

50th anniversary of first microbes in orbit

On November 3, 1957, life-forms first hitched a ride on space-faring hardware. Riding inside spacecraft, terrestrial life ventured to the Moon and far beyond (and may even have survived there for years). The vast majority of Earth creatures now living off the planet are almost too small to be noticed, but their future impact may be far larger than our own. And it all started 50 years ago this month.

The doomed pooch "Laika" wasn't the only passenger on Sputnik-2 in 1957. The dog carried an array of microorganisms that infested every nook and cranny of her body. And although the dog died within a few hours from a thermal-control-system failure (a fact the Russians concealed for decades), living organisms likely continued to thrive for the nearly 6 months the satellite remained in orbit. Temperatures inside the inert vehicle were well within the range in which Earth life can function, and the pressurized cabin would have remained intact.

A decade later, an even bolder small step for Earth germs occurred when a worker at a spacecraft workshop in California sneezed on a television camera he was assembling. Installed in the Surveyor-3 Moon lander, the device landed on the Moon in April 1967. Apollo-12 astronauts retrieved samples of the lander in November 1968. Laboratory testing of several spots inside the camera for microorganisms showed one sample contained viable human-borne germs.

This test's interpretation remains dubious. The tester was so skeptical of positive results, he was careless with quarantine protocols and laid the sampling swabs on a surface outside of the controlled area. So, the germs could have been his own. Still, the coincidence that the one success was with the swab from the most interior section of the camera remains suggestive.

The idea that microorganisms could have survived a trip to the Moon and then 2½ years of lunar surface temperature and radiation conditions remains plausible; conditions in the camera housing were calculated to always have been within known survival ranges for Earth life. That idea has a broader but still widely unrecognized implication: Such conditions — exposure to terrestrial contamination during manufacture and then protection within survivable environments — also apply to dozens of other space vehicles (particularly Russian ones, where pressurized canisters hold the electronics) launched toward the Moon, Mars, and Venus.

K-9 CARRIER. **The Russian canine "Laika" launched into space aboard Sputnik-2 November 3, 1957, carrying a host of microorganisms.** NASA

It's difficult to imagine that none of these vehicles were contaminated, and it's unknown how long the spores can survive in a dormant state. Maybe someday it will be feasible to retrieve one of those early probes and take a look.

Closer to Earth but still in space, microbial growth is strikingly prolific on long-term space stations, such as Skylab and the Russian Mir station. On Skylab, bacteria probably thrived for years on garbage and human waste in the craft's trash module. On Mir, fungi colonies grew on portholes (feeding on human skin peelings) and were so thick they obscured the view. The fungi also excreted highly corrosive waste products that etched the porthole glass and its titanium frame. Russian scientists found that the fungi and other microorganisms mutated wildly in the higher radiation levels of space.

Those "space colonies" ended in extinction when Skylab burned up over the Indian Ocean in 1979 and Mir in 2001, but the International Space Station is the latest host for Earth life. Humans, and small numbers of their experimental animals, are minority colonists there. Microbes may be small, but they represent the largest number of life-forms to venture out into the cosmos. **— JAMES OBERG**

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Does the competition stack up to the Astro-Tech?

Astro-Tech AT90EDT **$1295**

The **AT90EDT** from **Astro-Tech** is a 90mm f/6.7 *triplet* apochromatic refractor that uses all premium Ohara glass, including FPL-53.

A similarly-priced 90mm competitor is only a doublet – not a triplet – and can't be collimated in the field for peak performance the way the AT90EDT can. Another competitor's triplet costs $700 more than the 90mm Astro-Tech triplet; takes 60 to 180 days to get; and doesn't come with a free hard case, like the *in-stock* AT90EDT. And Astro-Tech's two-year warranty is twice as long as the higher-priced competitor.

Does the competition stack up to the 90mm Astro-Tech? Doesn't sound like it.

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Not only does the **Meade mySky** electronic travel guide to the heavens locate and identify 30,000 celestial objects for you with point and click simplicity, it shows you full-color images of many of them. You see and hear exciting multimedia presentations on its 480 x 234 pixel LCD screen and through its high fidelity earbuds, with color video, audio, still images, sky maps, and text.

An optional cable lets you connect the GPS-based mySky to your Meade AutoStar-equipped scope for point and go-to viewing, or add GPS to your non-GPS computerized Meade scope.

There's a reason Celestron calls them *Advanced.*

6" Celestron C6S-GT SCT **$999**

Celestron Advanced Series scopes combine great optics and a reliable German equatorial mount with the latest in computerized go-to technology to produce some advanced updates of old favorites.

Each Celestron Advanced Series scope has a stable and precise equatorial mount, dual-axis DC motor drives, advanced NexStar computer hand control with a 40,000 object library of celestial objects it can locate and track for you, sky-mapping software on a CD-ROM, an eyepiece, finderscope, and more.

Here are the *freight-paid* prices on the many Celestron Advanced Series go-to telescopes we ship from our stock.

C80ED R-GT, 3.1" ED refractor **$1099**
C100ED R-GT, 4" ED refractor **1574**
C130 MAK-GT, 5" Maksutov **1029**
C6 N-GT, 6" reflector **799**
C6 R-GT, 6" refractor **1069**
C6 S-GT, 6" Schmidt-Cassegrain **999**
C8 N-GT, 8" reflector **1019**
C8 S-GT, 8" Schmidt-Cassegrain **1514**
C9¼ S-GT, 9¼" Schmidt-Cassegrain ... **1999**
C10 N-GT, 10" reflector **1199**
C11 S-GT, 11" Schmidt-Cassegrain **2279**

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Meade LXD75 go-tos are out of this world.

Meade SN-6 LXD75 6" Schmidt-Newtonian **$999**

Looking for excellent optics, a very stable and advanced equatorial mount, fully computerized go-to operation, and a sensible price? Look no further than the **Meade LXD75** telescopes. Take your pick from these sizes and optical types:

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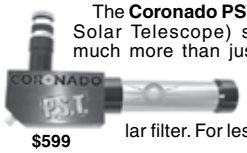
AR-6 6" f/8 refractor **1199**
SN-6 6" f/5 Schmidt-Newtonian **999**
SN-8 8" f/4 Schmidt-Newtonian **1199**
SN-10 10" f/4 Schmidt-Newtonian **1399**
SC-8 8" f/10 Schmidt-Cassegrain **1499**

Each has excellent optics (including some *very* fast wide field Schmidt-Newtonian reflectors); a solid LXD75 mount with premium features like a built-in illuminated polar axis finderscope; an adjustable height tripod; a big 8 x 50mm finderscope; a Super Plössl eyepiece; battery-powered 2-axis motor drive; AutoStar computer hand control; and much more.

The Coronado PST. Seeing sunspots is just the start.



$599

The **Coronado PST** (Personal Solar Telescope) shows you much more than just the sunspots seen with an ordinary solar filter. For less than cost of some premium eyepieces, the H-alpha filter in the PST shows you the ever-changing drama of solar flares and prominences exploding before your eyes.

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$69.95

The **Astro-Tech** *dielectric* 1.25" star diagonal is a *Sky & Telescope Hot Product for 2007*. It has 99% reflectivity *46-layer* dielectric mirror coatings. Its compression ring eyepiece holder won't scratch eyepieces. At only $69.95, it certainly *is* a best buy. And it's one of *five* great-value dielectric diagonals from Astro-Tech.

"Ritchey-Chrétien-like" performance . . . at only a fraction of an R-C's price.

Meade 8" f/10 LX200R Ritchey-Chrétien **$2699** *freight paid*

Astronomy said that Meade's new catadioptric design "delivers Ritchey-Chrétien-like performance at a fraction the cost." And *Sky & Telescope* said that Meade's new catadioptric "does indeed perform like a Ritchey-Chrétien."

Why pay $14,000 to $34,000 for the flat field of a true Ritchey-Chrétien reflector optical tube – and still have to pay for a mount? You can get the catadioptric that reviewers call "Ritchey-Chrétien-like" in a complete telescope and go-to mount combination starting at under $2700!

Meade 8" to14" LX200R go-to scopes usually ship from our stock, so you can get yours fast.

Here are the *freight-paid* prices on the Meade LX200R catadioptrics that we normally ship from our stock:

8" **LX200R,** on go-to mount with tripod ... **$2699.00**
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Because of their weight, these 16" LX200R scopes ship to you via truck from Meade.

16" **LX200R,** on altazimuth tripod **$12,999.00**
16" **LX200R,** on altazimuth pier **12,999.00**
16" **LX200R,** on equatorial pier **13,299.00**

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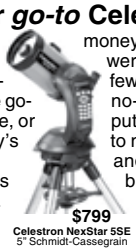

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Celestron NexStar 5SE 5" Schmidt-Cassegrain

The best 1979 Celestron C8, which we sold back then for $1295, would cost $3709.28 in today's inflated dollars – but wouldn't have the go-to computer, multicoatings, DC drive, or quality Plössl eyepiece of today's $1399 **Celestron NexStar 8 SE.**

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NexStar 5 SE, 5" Schmidt **799**
NexStar 6 SE, 6" Schmidt **999**
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The hot Celestron SkyScout. In stock now.

$399

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CLEAR LANE. The gap between HD 98800's dust rings may be swept clean by an undetected planet, or by gravitational effects from an orbiting star pair.

Quadruple star system may host planet

A planet may be present in the quadruple star system HD 98800, suggest Spitzer Space Telescope data. The stars lie 150 light-years away in Hydra.

The system consists of two pairs of stars separated by about 4.6 billion miles (7.5 billion kilometers), or a little more than Pluto's average distance from the Sun. A dusty disk surrounds one pair of stars.

Elise Furlan at the University of California, Los Angeles, and colleagues used Spitzer to reveal that the disk comprises two rings separated by a gap about 4 times the Earth-Sun distance. The inner ring isn't stable — the astronomers suspect it's continuously replenished by dust falling in from the outer ring.

"Typically, when astronomers see gaps like this in a debris disk, they suspect a planet has cleared the path," Furlan says. However, the stellar pair beyond the disk could open the gap through resonances, much as Saturn's moons create gaps in its rings. For the moment, she says, the presence of a planet is "just speculation." — **F. R.**

Japan's Moon mission delayed

Japan's Selenological and Engineering Explorer (SELENE) missed its August 16 launch date. JAXA, Japan's space agency, says a technical problem involving the ambitious lunar orbiter's two subsatellites led to the postponement.

Plans call for SELENE to spend a year mapping lunar resources. The subsatellites are to be deployed by the main spacecraft, which will fly 60 miles (97 kilometers) above the Moon's surface.

Satellite components were improperly installed, JAXA says. The $264 million lunar mission is 4 years behind schedule. — **F. R.**

JAXA

SETBACK. Japan scrubbed the launch of its SELENE lunar orbiter. Inspections showed components in a pair of subsatellites (top, in this illustration) were improperly installed.

BRIEFCASE

Pulsar detected

Astronomers from the ASTRON Radio Observatory and the University of Amsterdam detected a new pulsar, PSR B0329+54. The scientists used the Westerbork Synthesis Radio Telescope (WSRT) at the LOFAR station in Exloo, Netherlands, to make the discovery. — **L. L.**

Sabotage at NASA

NASA announced July 26 a space-program worker intentionally damaged two computers: one intended to fly aboard space shuttle Endeavour in August and another, ground-based computer. Authorities didn't release the name of the subcontractor. — **L. L.**

Cold robots

In July, scientists operated two NASA robots at Haughton Crater on Devon Island, Canada. The location's extreme environmental conditions and lack of infrastructure are similar to what NASA expects during its planned return mission to the Moon in 2020. — **L. L.**

25 years ago in *Astronomy*

November 1982

In the November 1982 *Astronomy*, physicist Jack R. Schendel outlined astronomers' knowledge of quasars. After scientists identified the first quasar in 1960, they discovered more quasars with increasing redshifts and energy outputs. Schendel's "Looking inside quasars" pointed out what little was known about quasars' energy sources.

Today, astronomers understand quasars are galaxies powered by supermassive black holes at their centers. In February 2007, the Sloan Digital Sky Survey (SDSS) found 4,000 quasars clustered in large dark-matter "halos" more than 10 billion light-years away. The SDSS discovery could reveal how black holes grew large enough to power such quasars when the universe was only a tenth of its current age. — **ERIN DOLAN**

November 1997

10 years ago in *Astronomy*

The November 1997 cover feature, "Bound for the ringed planet," anticipated the Cassini spacecraft's 2004 mission to Saturn. Author Josh Rogan hoped Cassini would pick up where previous missions left off. The 1981 Voyager 1 and 2 flybys lasted only a few hours, but Cassini planned to return years of data about Saturn's moons, magnetic environment, and rings.

On July 1, 2004, Saturn's gravity captured Cassini, and the spacecraft entered orbit. The Cassini image team has discovered 5 more moons there, bringing the total to 60 as recently as July. Cassini will begin its 52nd revolution of Saturn November 5, and it will complete 74 orbits by the time its 4-year tour is over. — **E. D.**

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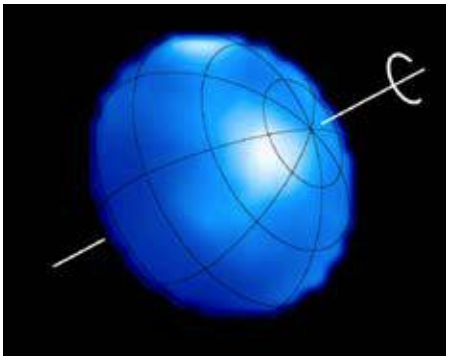

MING ZHAO (UNIV. OF MICHIGAN)

TURN, TURN, TURN. Sun-like star Altair spins completely on its axis every 6½ hours, causing its midsection to bulge.

Spinning Altair imaged

Astronomers have created the first detailed image of a Sun-like star: Altair, the brightest star in the constellation Aquila the Eagle. Altair is also a so-called rapid rotator, completing one revolution every 6½ hours. The spinning causes the star to bulge 14 percent wider along its equator than around its poles.

To image fast-spinning Altair, scientists — led by astrophysicist John D. Monnier of the University of Michigan in Ann Arbor — combined light from four telescopes at Mt. Wilson Observatory in California. The multiple-scope configuration, called the CHARA interferometer and operated by Georgia State University, enabled the astronomers to image the star's surface. In a single telescope, even a large and powerful one, Altair would appear only as a bright point of light. The CHARA interferometer has a maximum effective aperture, or light-gathering area, of 820 feet (250 meters).

Monnier says the new observations, reported by his group May 31 online in *Science Express*, will help theorists pin down the inner workings of rapid rotators. Spinning fast causes materials in a star to mix differently than in a normal star. It also affects heat distribution: Temperatures on Altair's surface vary by nearly 3,600° Fahrenheit (2,000° Celsius). — **DANIEL PENDICK**

Tipsy Mars

Did Mars once sport a vast ocean thousands of feet deep? Yes, according to a study in the June 14 issue of *Nature*.

In the 1970s, the Viking spacecraft spotted ancient shorelines, dubbed Arabia and Deuteronilus, in the planet's northern lowlands. In the 1990s, measurements by the Mars Global Surveyor (MGS) spacecraft showed the shorelines are wavy instead of level, like any shoreline would be. This cast doubt on speculations the Red Planet was once blue and watery.

Now, a team led by University of California, Berkeley, researcher J. Taylor Perron argues that, starting about 2 billion years ago, a redistribution of mass in Mars' interior forced the planet's crust to reorient itself. As the crust shifted relative to the planet's spin axis, the once-level shorelines of Arabia and Deuteronilus warped. The shift tipped the planet's massive Tharsis bulge closer to the equator, its most stable location, whereas the ocean basin shifted north, to its present position. — **D. P.**

J. TAYLOR PERRON/UC BERKELEY

OCEAN VIEW. This artist's view shows Mars as it might have appeared 2 billion years ago, with an ocean comparable in scale to Earth's Pacific.

Space port blast kills three

A July 26 explosion at the Mojave Air and Space Port in Mojave, California, about 80 miles north of Los Angeles, injured three people and killed three others. Two died July 26, and a third person died the following day.

All six people were employees of Scaled Composites. Aerospace engineer Burt Rutan founded the aerospace development company. Rutan designed space-tourism company Virgin Galactic's prototype spacecraft, SpaceShipOne.

The blast occurred during a test of nitrous-oxide-fueled rocket motor components for SpaceShipTwo — Virgin Galactic's second spaceship. At the time of the explosion, nitrous oxide was flowing through the motor's fuel injectors during a "cold fire test." "We were doing a test that we believed was completely safe," said Rutan. "We don't know why it exploded." — **LAURA LAYTON**

Early universe was more active

Scientists using NASA's Chandra X-ray Observatory have discovered supermassive black holes grow faster in younger galaxy clusters than they do in older ones.

"In a few nearby clusters we've seen evidence for huge eruptions generated by supermassive black holes. But this is sedate compared to what might be going on in younger clusters," says Jason Eastman of Ohio State University.

Eastman is the lead author of a survey that compared the fraction of active galactic nuclei (AGN) in four distant galaxy clusters with that found in nearby clusters. AGN are galaxies with bright cores, likely fueled by matter falling into supermassive black holes. The distant galaxy clusters, which formed when the universe was about 58 percent of its current age, contain about 20 times more AGN than the nearer, older clusters the scientists used for comparison. The older clusters formed when the universe was about 82 percent its current age.

These findings suggest the universe contained more AGN 10 billion years ago, when galaxy clusters began forming. Eastman suggests these youthful galaxy clusters grew quickly because they had larger quantities of dust and gas available to consume. The results appeared July 20 in *The Astrophysical Journal Letters*. — **L. L.**

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The secret lives of black holes

A black hole's spin may power gamma-ray bursts and galactic jets. But its rotation has been hard to measure — until now.

/// BY STEVE NADIS

A black hole's extreme gravity takes us to the very limits of physics — and about as far from everyday experience as we can get. At its central singularity, density and curvature race toward infinity, space and time come undone, and the tools of conventional physics are useless.

Yet, in an irony worthy of its subject, black holes boil down to something rather simple. As University of Texas physicist John Wheeler famously said, "Black holes have no hair" — that is, no details. The only quantities an outside observer can glean about a black hole are its mass and spin. The complex history of the stuff that made its way inside the black hole — as a dying star or a shredded galaxy — is simply radiated away.

"That's the miracle of a black hole," explains Ramesh Narayan of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. "If you can measure its mass and spin, you have, in a sense, obtained the complete story."

Steve Nadis, *a frequent* Astronomy *contributor, keeps tabs on astrophysics advances from his home in Cambridge, Massachusetts.*

DOES A BLACK HOLE'S ability to launch powerful jets arise from its surrounding gas disk? Or do these events somehow extract energy from the spinning black hole, which acts like a giant flywheel? Theorists have debated these questions for 30 years, but understanding what's happening requires measurements astronomers only now are able to make. ALL ILLUSTRATIONS: *ASTRONOMY:* ROEN KELLY

While spin is an essential piece of data for understanding black holes themselves, it's also crucial for understanding how black holes influence their environments. Now, astronomers have found ways to measure a black hole's spin.

Two numbers

Although a black hole appears simple from a distance, it undergoes complex interactions with the hot gases swirling around it. This is especially true for a rapidly rotating black hole. By virtue of its powerful gravitational field, the spinning hole literally drags space-time along with it. So, any inquiry into how black holes interact, says CfA astronomer Jeffrey McClintock, must begin with mass and spin.

For stellar-sized objects in X-ray binary systems, mass calculations are reasonably straightforward. Astronomers record how fast the companion star circles around the black hole, and, from this, they infer its mass. In fact, astronomers have this information for more than 20 stellar-mass black holes.

Unfortunately, this technique doesn't work for supermassive black holes, which range from a million to a billion suns. It's usually impossible to see stars moving around a galaxy's center, so scientists may never accurately know the mass of its black-hole behemoth.

Until recently, measuring a black hole's spin was beyond astronomers' grasp. Scientists quantify a black hole's rotation using a dimensionless parameter called a* (pronounced "a-star"). It ranges from 0 — for a non-spinning, so-called Schwarzschild-type black hole — to 1, an object spinning as fast as general relativity will allow.

Three techniques for determining a* now are on the table. Astronomers have a fourth ready to implement, but they'll need a new space observatory to do so. It's an exciting time for black-hole researchers.

Fit the continuum

McClintock and Narayan are pioneering an approach called continuum fitting. It involves equal parts theory and observation. They study X-ray binary systems, where a companion star reveals the presence of a stellar-mass black hole. This lets them get a good fix on the black hole's mass — the starting point for their analysis.

The black hole's intense gravity strips gas from the neighboring star. The gas spirals toward the hole and surrounds the invisible object in an accretion disk of hot plasma. Temperatures approaching 20 million kelvins occur on the disk's inner edge, where the gas moves the fastest.

This hot material radiates X rays until the gas reaches its innermost stable circular orbit (ISCO). After that, the gas plunges toward the hole so rapidly, it gives off no significant radiation.

McClintock and Narayan analyze the overall continuum spectrum of X-ray emissions, ignoring individual spectral lines, to gauge the gas temperature. From this, they can deduce the hole's ISCO because the closer a clump of gas gets to the hole, the greater the hole's gravity affects it, which makes the gas orbit faster and heat up due to friction. But a hole's ISCO radius varies with its spin, according to the precepts of general relativity.

One object spins more than 950 times a second — within 2 percent of the maximum value.

By knowing the radius, astronomers can determine how fast the black hole spins. A non-rotating, 10-solar-mass black hole has an ISCO of 56 miles (90 kilometers). If the same black hole were, instead, spinning at the maximum rate (a* equals 1), its ISCO would shrink to 9 miles (15 kilometers).

Using data collected by NASA's Rossi X-ray Timing Explorer (RXTE) satellite, McClintock, Narayan, and four colleagues determined spins for three black holes. Shane Davis at the University of California, Santa Barbara, measured a fourth.

One object — GRS 1915+105 — stands out from the crowd with its ultra-fast rotation. It spins more than 950 times a second, more than 98 percent of the maximum value relativity allows.

University of Maryland astrophysicist Chris Reynolds cautions the basic reasoning is sound, but he's less confident about the details. He wonders: "Do we understand the spectrum well enough to say the spin rate is 0.98 rather than 0.95?"

Iron lines

McClintock and Narayan disregard individual lines within a binary's X-ray spectrum, but other astronomers focus on one of the best-studied spectral features — the iron emission line. This feature blurs near a black hole due to an effect called gravitational redshift. As gas closes on the black hole, time runs slower.

"An emitting atom is like a clock," Reynolds explains. "The frequency of emission gets lower and lower as you approach the black hole." By analyzing this spectral line, he and other investigators can determine the extent of gravitational redshifting and surmise how close to the black hole the accretion disk extends. As with continuum-fitting, the iron line tells astronomers the ISCO's radius, which, in turn, tells scientists the hole's spin.

So far, astronomers have applied the technique to a 10-million-solar-mass black hole in the center of the spiral galaxy MCG–6-30-15. The result was an a* measurement of 0.987. In other words, this object appears to be spinning at 98.7 percent of its theoretical limit. Before Reynolds starts trumpeting that number, however, he wants to make absolutely sure he's really seeing the ISCO.

Song of the black hole

Other astronomers are taking advantage of the fact that some stellar-mass black holes "sing" at least part of the time. They emit high-frequency notes known as quasi-periodic oscillations.

The oscillation frequency tells researchers how hot the X-ray-emitting gas orbiting the black hole is. This, in turn, reveals the orbital radius of the gas. If that radius turns out to be smaller than the ISCO of a non-rotating black hole, they conclude the object is spinning.

But there's a problem. Says Ron Remillard at the Massachusetts Institute of Technology (MIT) in Cambridge: "We still can't convert these oscillations into actual spin numbers." There are several models for the oscillations, and each one yields a different spin.

Black-hole anatomy

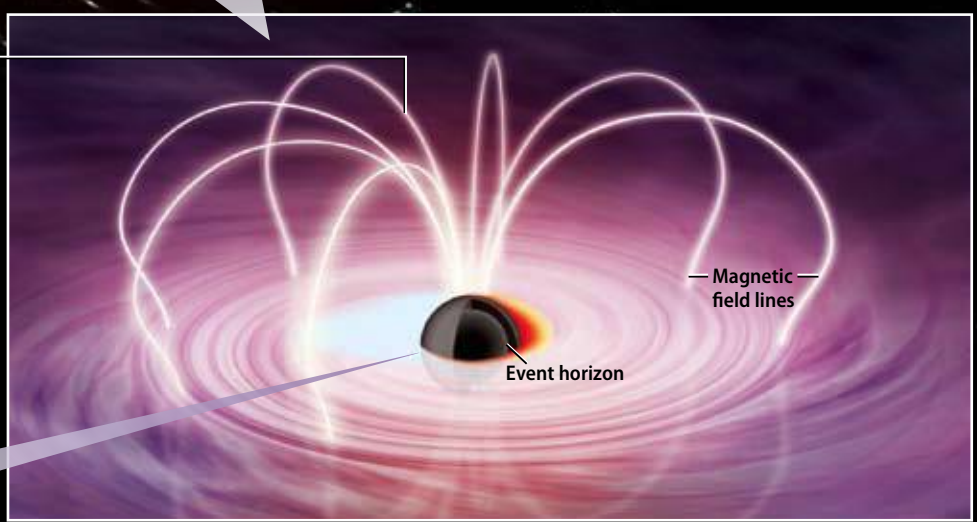
GRAVITATIONAL LENSING
Light from objects behind the black hole is reddened and distorted by the hole's gravity.

DOPPLER SHIFT
At left, radiation from gas spinning rapidly toward the observer shifts to higher energy (blueshifted). Gas at right rotates away from the observer, and its emission is redshifted.

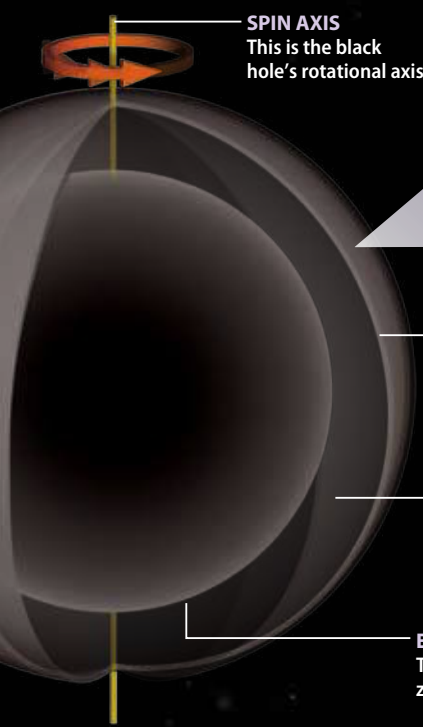
INNER ACCRETION DISK
Matter falling toward the black hole collects in a disk that surrounds it. Friction heats the gas.

GRAVITATIONAL REDSHIFT
Emission from gas in front of the black hole also is redshifted, in part because photons lose energy traveling out of the black hole's gravitational field.

DISK MAGNETIC FIELD
The disk's magnetic field becomes amplified and forms a corona near the hole. Magnetic field lines can extract energy from the black hole. This could either accelerate a jet of matter or, as shown here, enhance the disk's X-ray emission.



SPIN AXIS
This is the black hole's rotational axis.



STATIC LIMIT
Inside this boundary, nothing can remain stationary, even if it moves at light-speed, because the spinning black hole's gravity drags space-time along with it.

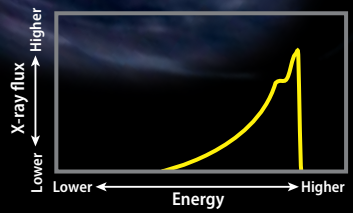
ERGOSPHERE
Between the event horizon and the static limit, in a region called the ergosphere, all trajectories must rotate in the same direction as the black hole.

EVENT HORIZON
This is the surface of no return — it marks the zone from which no matter can escape.

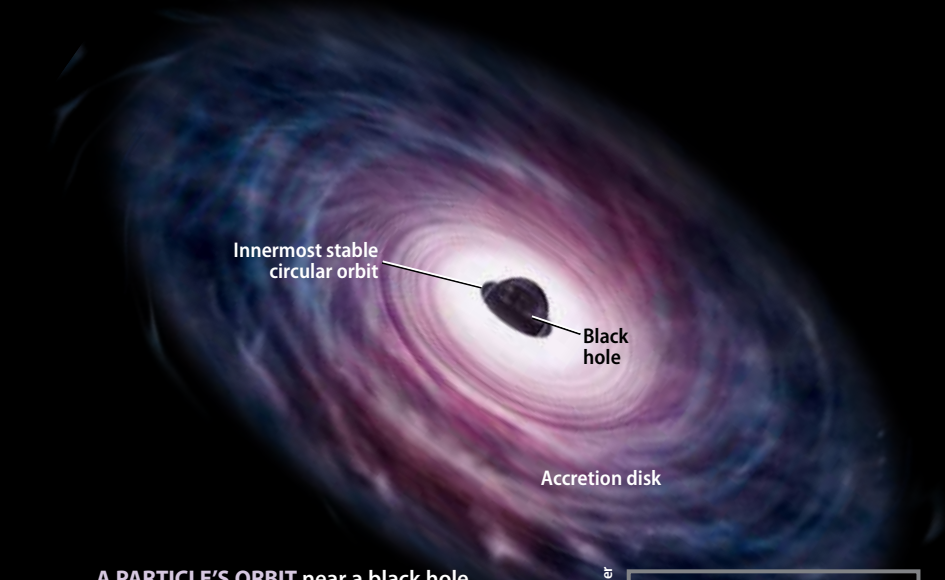
MOST OF A BLACK HOLE'S rotational energy resides in the ergosphere, a region where any object must rotate in the same direction the hole spins. Its actual size in the sky would be less than 1 millionth of an arcsecond — comparable to newsprint placed on the Moon. Space-based X-ray interferometers could achieve such resolution.

Non-spinning black hole

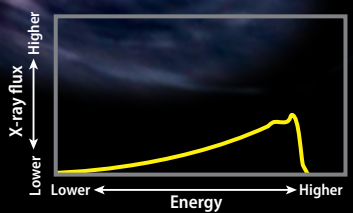
ASTRONOMERS USING NASA'S Chandra X-ray Observatory and the European Space Agency's (ESA) XMM-Newton satellite studied iron emission in the hot gas of a black hole's inner accretion disk. Atoms closest to the black hole emit radiation at lower energy, which produces a strongly skewed signal.



Spinning black hole



A PARTICLE'S ORBIT near a black hole depends on how the hole warps space-time, which, in turn, also depends on how fast the black hole spins. A spinning black hole drags space around with it and allows atoms to approach closer than is possible for a non-spinning black hole. The tighter orbit produces stronger gravitational effects, which means more of the X rays from iron atoms shift to lower energies.



The approach still has great promise, Remillard says, "because these frequency measurements are good to 10 percent." What's more, the oscillations seem to come in pairs of frequencies that have a 3:2 ratio (such as 450 and 300 hertz). Those frequencies don't change over time, even if the black hole goes silent for a year or more before singing again.

Given the possibilities for a crisp, clear measurement, says McClintock, "This might prove to be the best way to get the spin, once we have a model that tells us exactly what's oscillating."

Turning to polarization

A fourth proposed strategy aims to exploit the expected polarization of X rays emitted from accreting black-hole systems. Both the curvature of space-time near the hole and the twist caused by the black hole's rotation could lend a preferred orientation to the electromagnetic waves. In principle, notes Reynolds, "The black-hole spin could show up in the polarization signal, assuming you know the polarization of the initial source, which is far from clear."

"This is unexplored discovery space," claims Jean Swank of NASA's Goddard Space Flight Center in Maryland. "These X-ray photons are carrying additional information that has never been studied."

The biggest problem with the technique is that it needs to be done from space, and no space mission designed to measure polarized black-hole X rays is even being planned. NASA scientists hope to install a polarization detector on Constellation-X, the agency's proposed next-generation X-ray observatory. But the future of this project itself remains uncertain.

"We'd like to have all four techniques established," McClintock says, because the spin calculation is complex. Many assumptions go into each calculation and uncertainties creep in at various stages. "But once you get the same answer from more than one technique, you know you're there," he says.

Memento

Astronomers aren't just interested in spin for spin's sake. They're convinced spin holds the key to solving many long-standing puzzles. It can tell us, for instance, how black holes are born and how they grow.

"The spin retains a memory of these things," Reynolds says. Such measurements

also can help investigators test ideas about how phenomena like astrophysical jets and gamma-ray bursts work.

Just what drives the violent jets emanating from black holes has been a mystery for at least 30 years. "The question, long debated, is whether the power behind jets and other phenomena derives from the black hole or from the accretion disk," explains Roger Blandford, an astrophysicist at Stanford University who has studied the problem since the 1970s. While others disagree, Blandford thinks the source is the black hole's rotation. The spinning hole acts like a "giant flywheel, with some of its energy there for the taking," he says.

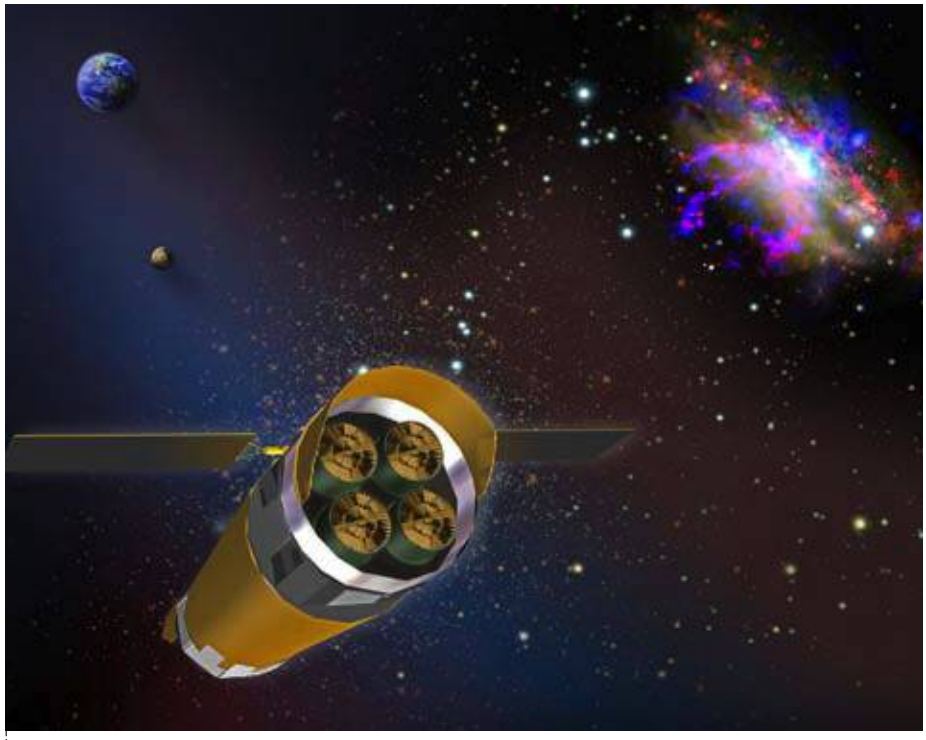
That seems plausible to McClintock. "Maybe jets are driven by the enormous spin of these black holes," he says, "but unless you have spin measurements, you can't test the theory." That's why he's intent on acquiring at least a dozen solid measurements. GRS 1915 offers an intriguing example: Its famous jets whisk matter through space at roughly 92 percent of light-speed, and its estimated spin approaches the theoretical limit.

"You'd really like to have spin measurements for a large number of jet-producing black holes," says David Meier at the Jet Propulsion Laboratory in Pasadena, California. "You'd look at all these black holes spinning at different rates, look at the distribution of jet power, and try to find a pattern." The good news, says Meier, is that we may soon be in a position to do it.

Jets and GRBs

Gamma-ray bursts (GRBs) have posed a similar challenge to theorists since satellites first detected them in 1969. Today's leading theories hold that GRBs occur when the cores of massive stars collapse into fast-spinning black holes.

Until recent measurements of objects like GRS 1915 or MCG–6-30-15, says CfA's Narayan, "We didn't know for sure that such objects existed. Based on the few data points gathered so far, it appears that rapidly spinning black holes are pretty common."



NASA'S PROPOSED Constellation-X Observatory would use at least four X-ray telescopes working in unison. The resulting measurements would have 100 times the sensitivity of NASA's Chandra X-ray Observatory or ESA's XMM-Newton, both currently in orbit. If funded in 2009, the mission could launch in 2017. NASA

Stan Woosley, an astrophysicist at the University of California, Santa Cruz, agrees. "We always thought massive stars must be rotating rapidly when they collapse, but for a long time all we've had is guesses." In some models, evolved stellar cores often don't rotate fast enough to power GRB jets. "It's nice to finally have some measurements to work with," he says.

Once astronomers have amassed many credible spin measurements, they may be able to test general relativity as it's never been tested before — within the universe's strongest gravitational fields.

"If there's a big surprise out there, if Einstein is wrong, one way to find out is by pushing these spin measurements," Reynolds says. Astronomers say NASA's proposed Constellation-X observatory offers the resolution needed to put relativity through such a test.

If Einstein is wrong, detailed data about spinning black holes offer scientists a way to find out.

At the same time, precise spin measurements also might lend support to the "no hair" theorem itself. If multiple approaches yield the same answers, Narayan explains, it would validate the notion that mass and spin tell astronomers everything about a given black hole.

That's a remarkable idea. "Consider anything else you might try to describe in nature, such as a simple grain of salt," McClintock suggests. "It would take trillions of numbers to specify the position of all the atoms and all the atomic states."

Or imagine a distant view of Earth. From far off, the only thing you can detect, the only thing that matters, is the planet's mass. "But as you get closer, you see oceans, mountains, trees, and people," Narayan says. You'd need a long list of numbers to describe it all.

Black holes are different. We can never see them directly. Instead, they make themselves known indirectly, through effects related to their intense gravity and rapid rotation. Together, mass and spin bring scientists closer to a black hole's abyss.

ONLINE EXTRA View animations showing the effects of spinning black holes at www.astronomy.com/toc.

Earth

AT THE SHORE of a Titan lake, liquid methane laps the coast as a blimp-like "aerobot" drops a tethered device to collect lakeshore mud for analysis. In the distance, clouds rain methane onto the surface, where it collects in low-lying areas of Titan's northerly "lake district." MICHAEL CARROLL FOR *ASTRONOMY*

of the outer solar system

Each Cassini flyby fills in details of this frostbitten saturnian moon shaped by forces identical to those that sculpted Earth's surface. /// **BY MICHAEL CARROLL**

A crescent Saturn slices an arc through a crystalline blue sky. Snow-dusted rocks tower above icy plains. This was the Titan of the 1940s, a world immortalized in the paintings of pioneering space artist Chesley Bonestell. In fact, his painting of Titan's surface, which graced the cover of Willy Ley's and Bonestell's 1949 bestselling book *The Conquest of Space,* has been called the best-known work of space art ever created.

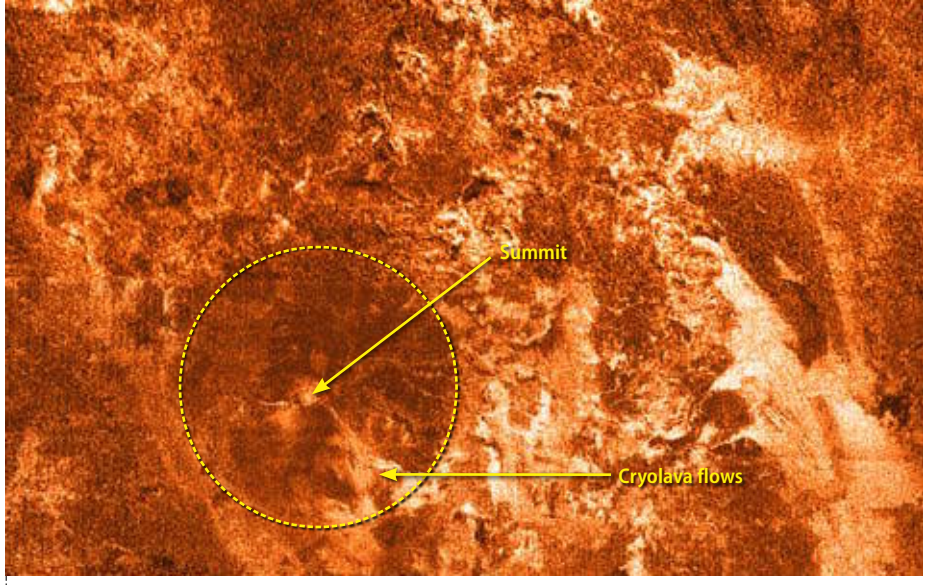
Bonestell's vision reflected the scientific thinking of the time. But research soon showed that Titan was not a clear-skied desert world. Instead, its ruddy hue traces to a thick shroud of orange smog. Discovery of methane in Titan's atmosphere raised the possibility of hydrocarbon seas. But the smog and Titan's great distance kept its secrets hidden.

After the Hubble Space Telescope provided tantalizing peeks under Titan's shroud in the 1990s, the smog lifted January 14, 2005. That was the day the European Space Agency (ESA) Huygens probe dropped into Titan's atmosphere and parachuted to the surface. And what did it see?

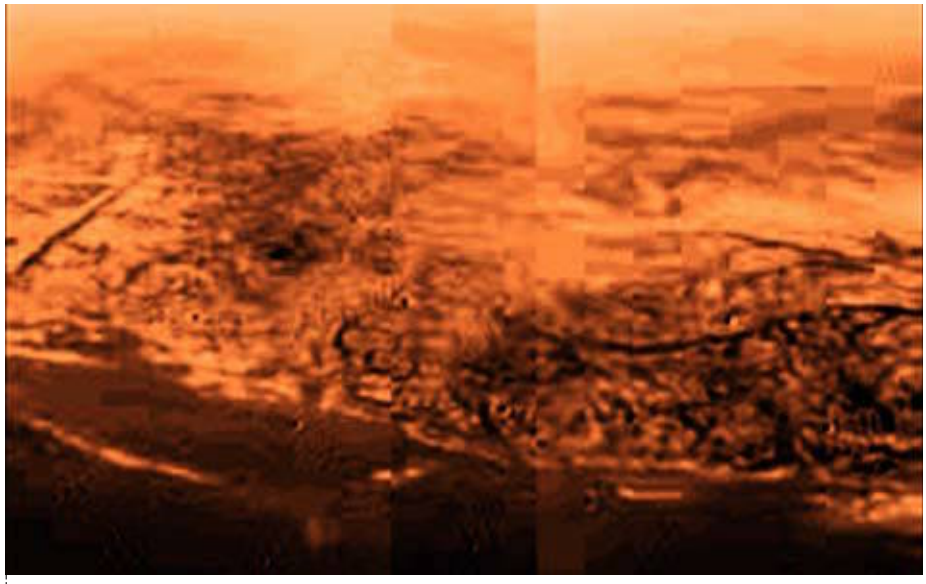
Earth.

"We now have the key to understanding what shapes Titan's landscape," mission scientist Martin Tomasko told reporters at ESA's headquarters in Paris. "Geological evidence for precipitation, erosion, mechanical abrasion, and other fluvial [liquid-driven] activity say that the physical processes shaping Titan are much the same as those shaping

AN INFRARED VIEW of Titan's surface reveals dark surface features but no fine details. Radar images ultimately unlocked Titan's secrets by peeling away the moon's obscuring clouds. NASA/JPL/SPACE SCIENCE INSTITUTE



MISSION SCIENTISTS initially thought this feature, Ganesa Macula, might be a meteor impact crater. But it turned out to be a wide, gently sloping "cryovolcano" that has erupted a slushy mix of water and ammonia from Titan's icy crust. NASA/JPL



GRAINY, UNFOCUSED, and distorted yet utterly remarkable, this mosaic of images from the descending Huygens probe offers a close-up glimpse of Titan's surface. Highland terrain laced with drainage channels slope to darker lowland areas. ESA/NASA/JPL/UNIVERSITY OF ARIZONA

Earth." And these processes would be utterly familiar to any first-year college geology student.

"We see dendritic channels, which are the result of liquid erosion," says Cassini imaging-team leader Carolyn Porco of the Space Science Institute in Boulder, Colorado. "We see dark hydrocarbons washed from the highlands, pooling in low-lying areas. We see aeolian [wind-driven] effects. We see cloud systems. In short, we are seeing earthlike processes, but they are occurring in unearthlike materials."

With every new flyby of Titan, Cassini paints a richer and more colorful portrait of Titan than even Chesley Bonestell could envision. We are finally beginning to understand Saturn's largest moon as a world in its own right, even though it seems just like home in some fundamental ways.

Early glimpses

To understand the scientific journey to Titan, we must look back in time. Voyager 1 flew past Titan in 1980, followed by Voyager 2 in 1981. The craft radioed back portraits of an orange-tinted orb with an atmosphere 1.5 times denser than Earth's.

Voyager flyby data fueled earlier suspicions that Titan's surface might harbor lakes or seas of the hydrocarbons methane or ethane, and that Titan's skies may drench the surface in a rain of hydrocarbon-based molecules — potential building blocks for organic life. Despite Voyagers' batteries of instruments, neither craft penetrated Titan's clouds to glimpse the landscape below.

The only way to unveil Saturn's mystery moon would be to observe it in wavelengths of light that pass through the obscuring cloud cover. In October 1994, flight engineers commanded the Hubble Space Telescope's Wide Field and Planetary Camera to observe Titan in near-infrared light. Infrared's long wavelengths bounced off surface features and then passed back through Titan's cloud cover out to space, where Hubble imaged them. The new Hubble snapshots revealed dark and light features on the surface. Could these be the predicted hydrocarbon oceans? Or were they just solid surface features?

The Cassini revolution

The answers would finally come with the Cassini-Huygens mission to Saturn. The Cassini orbiter carries synthetic aperture radar, similar to the radar instrument the Magellan spacecraft used in 1990–1994 to peer through Venus' cloud cover and map its surface. Cassini's imaging system also peers through the clouds in near-infrared, just like Hubble did. The European Huygens probe would complete the reconnaissance by parachuting to Titan's surface while sniffing its atmosphere and taking snapshots of the terrain below.

Michael Carroll *is a space artist and science journalist in Littleton, Colorado. His work appears frequently in* Astronomy.

Visible and infrared imaging from Cassini's first Titan flyby, in October 2004, revealed a surface with dark and bright regions in complex patterns. No features were immediately recognizable as mountains, rivers, or meteor impact craters.

"At first the images were very ambiguous," Porco recalls. "We were looking through layers of haze. We saw no shadows. We couldn't say what was up or down."

Cassini's radar helped clarify things. Microwaves beamed from Cassini's main antenna pierced Titan's atmospheric haze, bounced off the surface, and returned to the craft. Patterns in the returning radar "echoes" provided clues to Titan's topography and surface composition, such as whether the dark patches were liquid.

Titanic volcanoes

The first sharp radar images came in a few days after Cassini's inaugural flyby of Titan. A radar scan along a strip nearly 5,000 miles (8,000 kilometers) long showed smooth plains and rugged highlands. But mission scientists also saw a prominent, 110-mile-wide (180 km) circular feature spanning the strip from top to bottom. They named the structure Ganesa, after the elephant-headed Hindu god.

The scientists wondered if Ganesa were a scar from a past meteor impact. A closer look showed otherwise. Ganesa appeared to be a volcano. "We realized it wasn't an impact feature, and then we saw similarities to pancake domes on Venus," explains Rosaly Lopes, a Cassini radar-team member at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

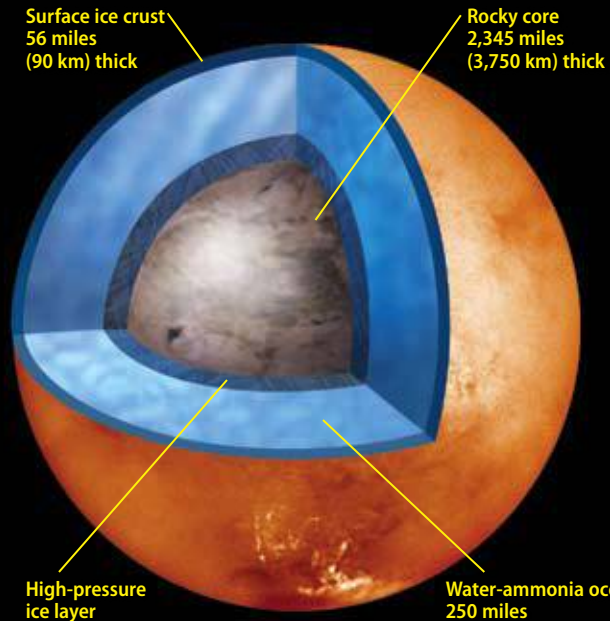
Pancake domes are flat-topped volcanic mountains on Venus built by eruptions of molten rock, or magma — just like volcanism on Earth. But Titan's surface, although hard as rock, is mainly frozen water. Instead of molten rock, Ganesa erupts a slushy "cryomagma" composed of melted water, perhaps mixed with ammonia.

"We now think that Ganesa may be a shield volcano," says Lopes, an expert in extraterrestrial volcanism who leads JPL's geophysics and planetary geosciences team. Volcanic shields consist of multiple runny lava flows that gradually form a broad, gently sloping structure resembling an upturned shield. Hawaii's Big Island is Earth's grandest shield volcano, and Ganesa looks eerily similar. This suggests they may have formed by the same basic process.

Inside Titan

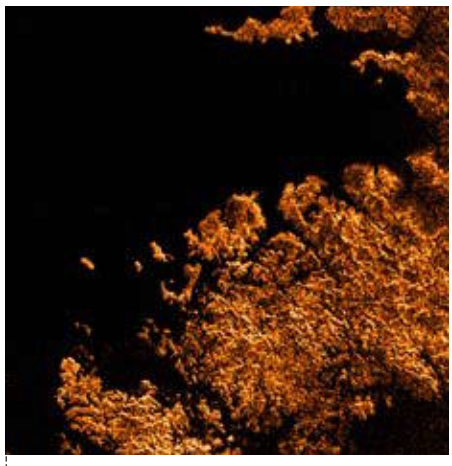
TITAN'S INTERIOR structure remains a mystery. But planetary scientist Giuseppe Mitri of the Jet Propulsion Laboratory has developed a theoretical model of Titan's interior that describes one possibility. In Mitri's model, Titan has a warm rocky core surrounded by a layer of compressed ice about 1.4 times denser than common ice. (The high-pressure layer formed as Titan was cooling and contracting in the early solar system.) An ocean of water and ammonia underlies Titan's frozen outer crust. *ASTRONOMY*: JAY SMITH

Illustration not to scale



Some cryomagma flows on Titan are massive. About 1,375 miles (2,200 km) from Ganesa lies a flow, named Rohe Fluctus, estimated to be 1,000 feet (300 meters) thick. To pile up that high, cryomagma would need to be thicker than a water-ammonia slurry. Lopes and several colleagues proposed in the February 2007 issue of *Icarus* that a dash of methanol would make the flows viscous enough to account for their thickness.

Cryovolcanism is not simply an occasional gurgle of slush; it's a major force for change on Titan. The flow dubbed Winia Fluctus covers at least 9,150 square miles (23,700 square kilometers), or slightly less than the area of Vermont. Sub-zero cryovolcanism may have substantially shaped Titan's icy surface, just as molten-hot volcanism has transformed Earth's rocky surface, over billions of years. And it may still. Mission scientists are on the lookout for signs of recent eruptions.



COMPLEX COASTLINES are common on Earth but also on Titan, judging from this Cassini radar image. Because the small, isolated islands follow the same trend as the peninsulas on land, this coast may be part of a flooded mountain ridge. NASA/JPL

Huygens away!

On December 24, 2004, the Cassini orbiter dispatched its hitchhiker, the European Space Agency's Huygens probe. Three weeks later, Huygens entered Titan's atmosphere and released a series of parachutes to slow its 2½-hour descent to the surface. The craft gathered data on atmospheric conditions and composition on its way down — data to feed computer models of Titan's atmosphere.

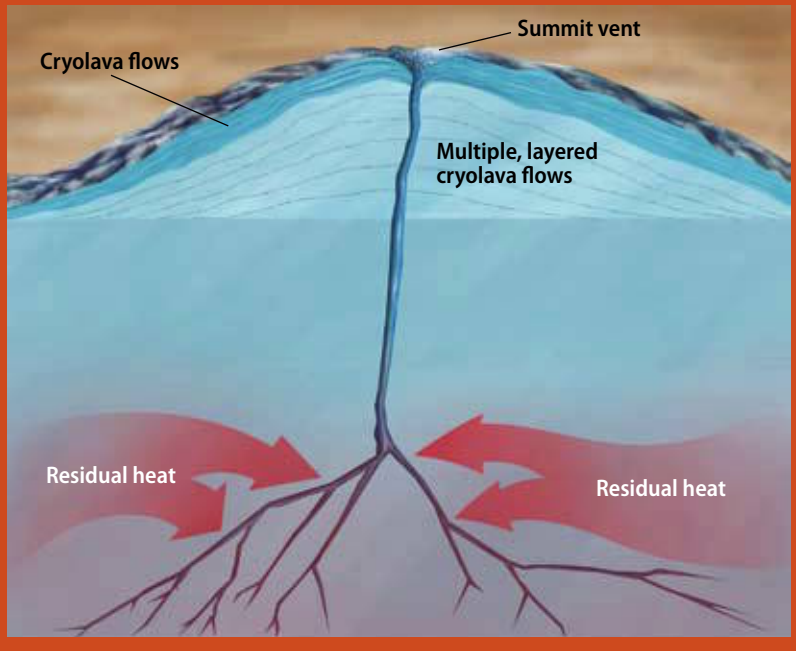
After passing through the cloud deck, Huygens snapped aerial photos of river-cut hills and flat regions that may be dry lakebeds. Artery-like systems of drainage channels went from highlands to lowlands. These so-called dendritic channels are the hallmark of surfaces on Earth drained by streams and rivers. But the liquid could not be water; at –291° F (–180° C), Titan is far too cold. It had to be methane, which is gaseous at earthly temperatures but remains a liquid on frosty Titan.

The big "aha" moment for the Huygens team arrived when the probe descended to

GANESA MAY BE similar to shield volcanoes on Earth, such as Hawaii's Mauna Loa. As shown in this artist's rendition, Ganesa has a broad base and gently sloping sides. Many cryolava flows, like the one perched in the foreground, built Ganesa over time. MICHAEL CARROLL

A GIANT METHANE cloud in Titan's north polar region may produce methane rain that collects in the moon's lakes. NASA/JPL

Cryovolcanism on Titan



ON TITAN, residual heat from the moon's formation may heat water and ammonia to form cryomagma. Ganesa sports a central vent where cryomagma flowed upward and spilled onto the surface. The summit vent may be connected to the subsurface zone of melting by a system of branching fractures. Right now, this vision of Ganesa's plumbing is plausible speculation. Cassini mission scientists have plenty of work left to do just to assess the extent of cryovolcanism on Titan and whether it actively shapes the moon today. *ASTRONOMY:* JAY SMITH

between 10 and 5 miles (16 and 8 km) above the surface. "This was the altitude at which Huygens saw dendritic channels," says Porco. "We could be confident the dark, meandering features in our images were probably eroded by liquid."

Huygens revealed surprises and confirmed suspicions. For one, methane vapor in the atmosphere remained near saturation, creating conditions for abundant rainfall. But where was the methane hiding?

"To have that much methane in the atmosphere, we really suspected that liquid bodies were lying down there somewhere, recharging the atmospheric methane," explains Rosaly Lopes.

Land of lakes

Soon the liquid bodies — or what mission scientists think are liquid bodies — came into view. In July 2006, Cassini's orbit carried it to 85° north latitude, farther north than on any previous pass. Its radar system returned images of channels, embayments, and very dark, well-defined areas with shorelines. Radar sees smooth regions (like a liquid surface) as dark, and these bodies were as dark as the system could detect. "Finally we have a source of all that methane," Lopes says. Many are oval or arc-shaped, but several have the appearance of liquid-filled calderas, features that form on Earth when volcanoes collapse.

Each additional Cassini radar pass returned additional evidence of river valleys, basins, and regions similar to embayed shorelines. One image included a dark, kidney-shaped feature resembling a lake the size of Lake Ontario. "It was the closest thing to a lake we had seen, but we couldn't be sure it was filled with liquid or with some sort of dark deposit," Porco recalls. "We were on the fence."

Several of the suspected lakes were ringed by concentric shorelines, like those formed on Earth when evaporation deposits minerals along a lake's rim. Mission scientists continue searching for evidence of scattering, a radar-echo pattern indicating wave action on a liquid surface.

The methane cycle

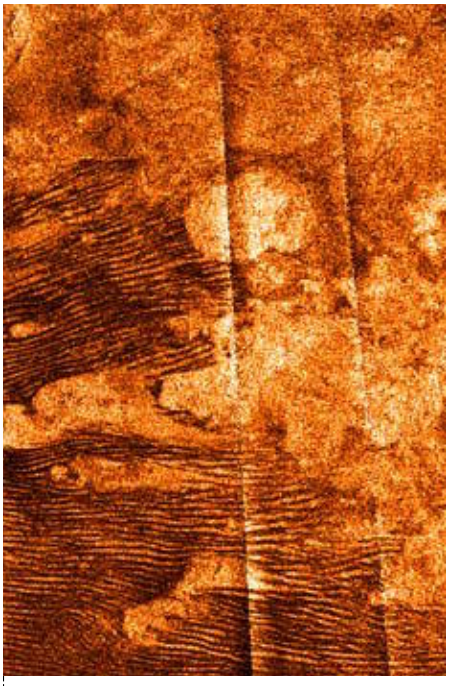
Both Huygens and Cassini confirmed that a constant methane drizzle falls over about half the moon's surface, thus explaining why Huygens landed in methane mud. "There appears to be more methane in the

atmosphere than on the surface," says astrobiologist Chris McKay of the NASA Ames Research Center in Moffett Field, California. "It would seem that the atmosphere has a bit more methane than it can hold."

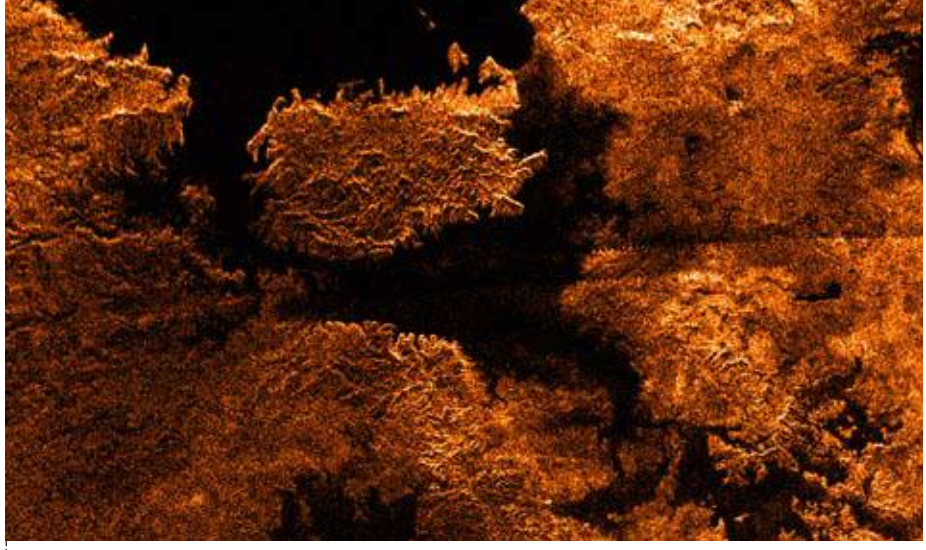
The rain forms in methane-nitrogen clouds at an altitude of 12.5 miles (20 km). Above that cloud deck, a gap of clear air underlies a high-altitude layer of methane ice crystals. The methane humidity increases closer to the poles, where the lakes were found.

Planetary scientists want to understand how methane moves from cloud to ground and back to cloud again. On Earth, the medium is water — solid, liquid, and gas. These materials shuttle between land and sea in a global "water cycle." Titan has an analogous cycle based on methane. "We don't yet understand the methane cycle on Titan," says McKay. "It was expected that there would be lakes over much of the surface, and we were surprised to find them only in the north polar regions."

It's winter in the north, accounting for methane lakes. When summer comes, the lakes may evaporate and reform in the wintry south. "Many people assume that these lakes are seasonal and will move to the south polar region when winter comes to that pole in 15 years," McKay explains.



DUNE FIELDS on Titan may consist of frozen methane or water-ice grains. The sheer scale of the dune fields, extending for hundreds of kilometers, hints at Titan's dynamic environment. NASA/JPL



WHILE FLYING over Titan's polar region, Cassini spied this island. At 56 miles (90 km) wide and 93 miles (150 km) long, it's roughly the size of Hawaii's Big Island. The largest lakes on Titan, like this one, appear to concentrate at the northernmost latitudes. NASA/JPL

One unsolved mystery is what mechanism recharges the methane cycle. Lopes and others think cryovolcanism may play a role. As interactions between sunlight and hydrocarbons in the upper atmosphere remove methane, cryovolcanism may release fresh supplies from below.

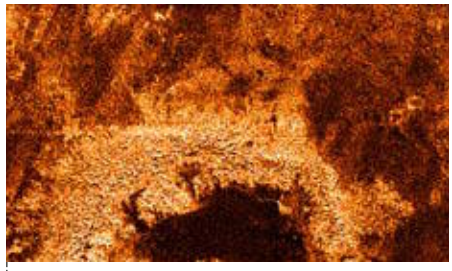
Brave new world

So far, the spectacularly successful Cassini-Huygens mission has revealed the broad brush strokes of Titan's geology and atmosphere, completely revising Bonestell's 1940s vision of this alien moon. Next come the fine touches and highlights, the important details of how Titan works. For example, we see vast fields of dunes, most likely composed of ice crystals. How do they fit into the liquid methane cycle?

"Huygens showed us that it rains on Titan," Lopes says. "But the dunes must form as dry particles. Many of these dunes are close to channels, so what is going on with this methane cycle? It may be that these regions go through periodic droughts, like in terrestrial deserts." Researchers hope future flybys will reveal more about the physical relationships between dunes and liquid surface methane.

Another Titan mystery concerns the handful of meteor craters spotted so far. The moon's frozen surface is as hard as rock. Impacting meteors excavate craters much as they do on Earth. The largest confirmed crater, Minerva, is a classic impact basin 50 miles (80 km) across.

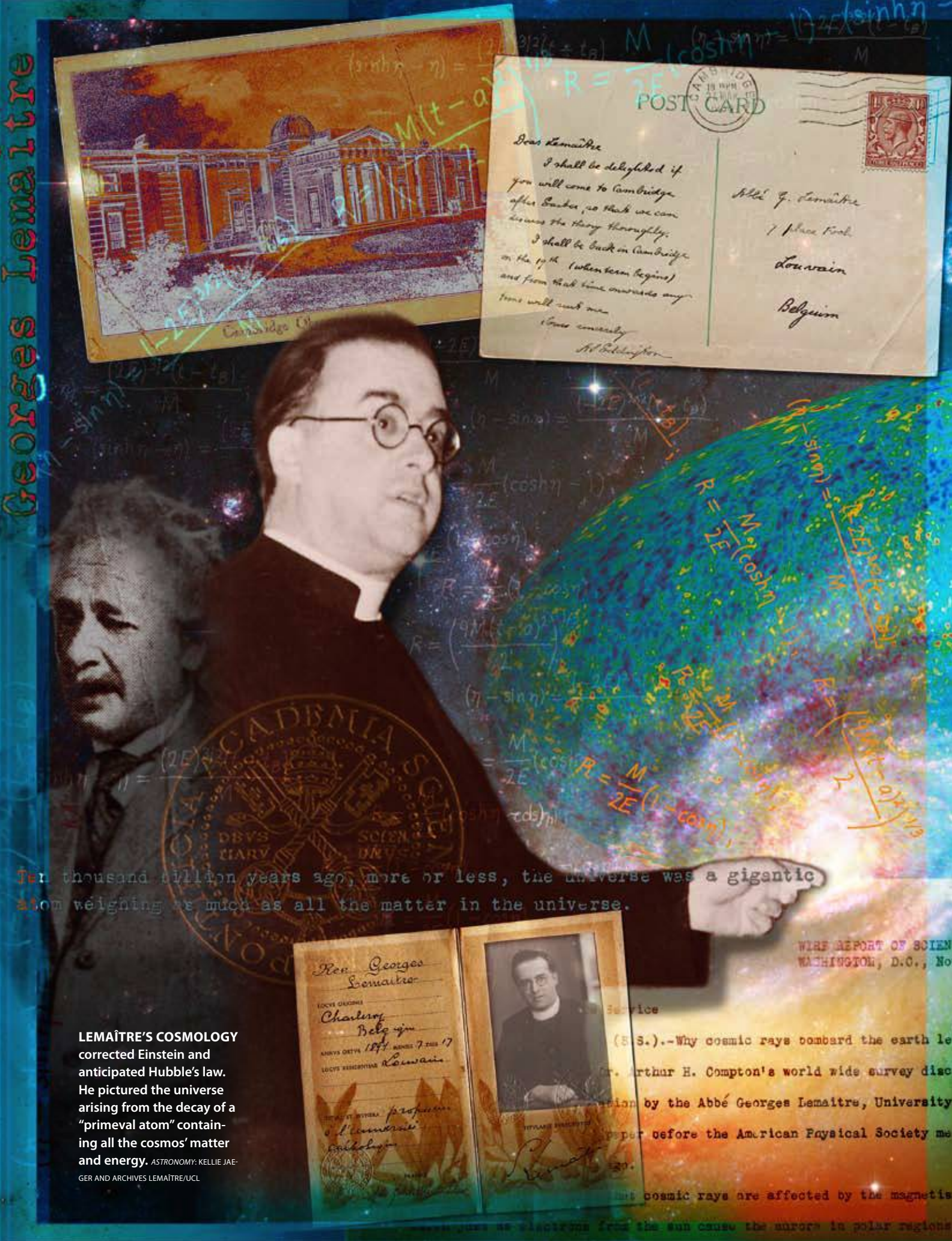
The odd thing about Titan's craters is the lack of smaller examples, in the range of 12 to 18 miles (20 to 30 km) in diameter. Computer models suggest Cassini's radar should be seeing these, but it doesn't. Where did they go? Does some as-yet-unknown surface process obscure the craters, or are they simply swamped in by organic particles raining from the sky?



CASSINI RADAR captured part of what might be an impact crater roughly 110 miles (180 km) wide. Only three craters are known on Titan now. Their rarity suggests active and recent processes smooth the moon's surface. NASA/JPL

As Cassini gathers more information on Titan, scientists anticipate more answers and even more mysteries. As the Cassini-Huygens team basks in well-deserved glory, NASA headquarters has requested studies for follow-up missions, including another Titan orbiter, a blimp-like "aerobot" probe to explore Titan's surface, and a more advanced Saturn orbiter designed to do multiple Titan flybys. The planned scientific armada will help discover more of the secrets Titan's clouds have kept veiled for centuries. "All craters on Titan are named after gods or spirits of wisdom," Lopes says. "To understand Titan, we'll need all the wisdom and help we can get!"

ONLINE EXTRA To see side-by-side comparisons of landforms on Earth and Titan, go to www.astronomy.com/toc.



LEMAÎTRE'S COSMOLOGY corrected Einstein and anticipated Hubble's law. He pictured the universe arising from the decay of a "primeval atom" containing all the cosmos' matter and energy. *ASTRONOMY:* KELLIE JAEGER AND ARCHIVES LEMAÎTRE/UCL

The priest, *the* universe, *and the* Big Bang

A Belgian priest's extraordinary insights anticipated modern cosmology's most fundamental ideas. /// BY YAËL NAZÉ

In the 1920s, American astronomer Edwin Hubble showed that so-called spiral nebulae are, in fact, other galaxies of stars, gas, and dust — complete "island universes" like our own. Most scientists then thought the universe was ageless and static — it had always existed and had always looked the same. But a few theorists working with Albert Einstein's relativity realized the equations implied an unstable universe, one in which the cosmos is either expanding or contracting.

A Belgian physicist and priest named Georges Henri Joseph Edouard Lemaître was the first to explore the physical nature and origin of an expanding universe. Decades later, astronomers gave his idea about cosmic creation the name we know it by today — the Big Bang.

Yaël Nazé *is an astrophysicist at the University of Liège, Belgium, where she studies massive stars and their environments. She enjoyed seeing Lemaître discussed in Dan Brown's 2000 novel* Angels and Demons *(Pocket Books).*

Origins

Lemaître was born July 17, 1894, in Charleroi, a medium-size industrial town in southern Belgium. He attended a Jesuit high school and, at 17, decided to become a civil engineer. In 1913, he entered the Catholic University at Leuven, but a year later World War I erupted; Germany invaded Belgium, and Lemaître volunteered for the army. The artilleryman was awarded the *Croix de Guerre* with palms for his distinguished service.

After the war, Lemaître took up his studies again, but this time turned toward mathematics and physics. He also decided to become a Catholic priest and entered the seminary at Mechelen after completing his doctorate. In 1923, the year Lemaître was ordained, Edwin Hubble proved that M31, the famous Andromeda Nebula, was really a distant galaxy.

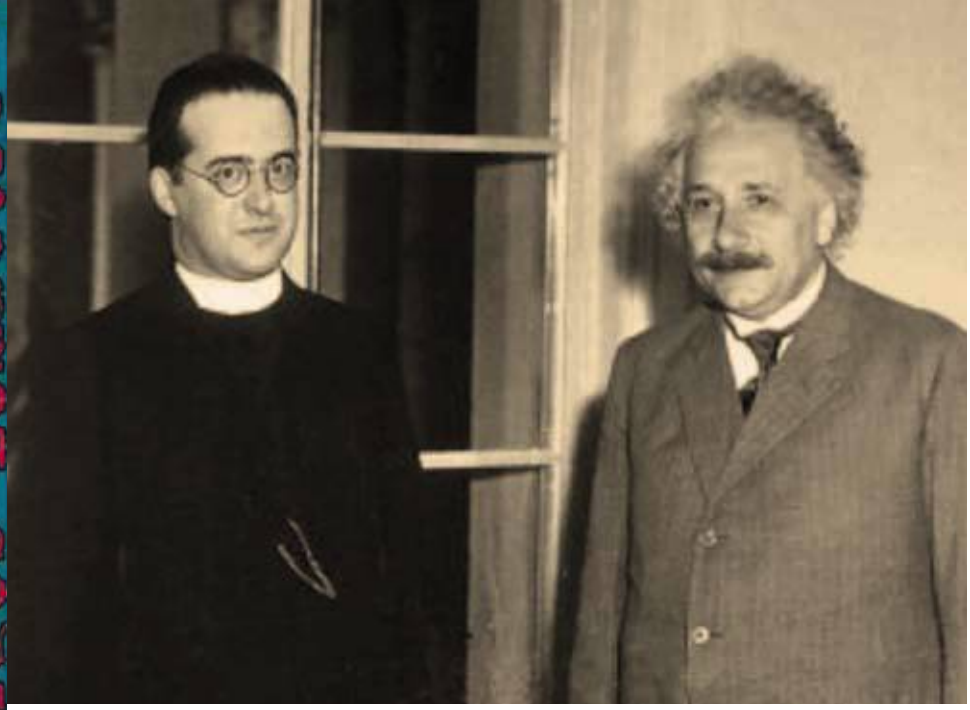
Lemaître's studies had introduced him to new fields of physics: quantum mechanics and relativity. He closely followed Arthur Eddington's eclipse expedition in 1919, which showed the Sun's mass displaced starlight by warping space-time, as Einstein had predicted. Lemaître wrote a comprehensive synthesis of Einstein's theories that impressed other Belgian scientists, and he received a grant to travel abroad and pursue his scientific work.

Lemaître headed straight to the University of Cambridge in England to meet Eddington, a man he much admired. He spent the following year working with Harlow Shapley at the Harvard College Observatory in Cambridge, Massachusetts, and began studying for another doctorate at the Massachusetts Institute of Technology.

Although he was a theorist, Lemaître considered observations the most important part of science. He took the time to visit many American observatories, including Yerkes in Wisconsin; Lowell in Arizona; Dominion in British Columbia; and Lick and Mount Wilson in California. He always connected his mathematical developments to actual astronomical data, an aspect of his work that made his conclusions difficult to brush aside.

Founding father

In 1926, Lemaître returned to Belgium to become a part-time lecturer at the Catholic University at Leuven. A year later, he published one of modern cosmology's founding texts. His paper, "A homogeneous universe of constant mass and growing radius accounting for the radial



EINSTEIN CALLED Lemaître's physics abominable when the two scientists first met in 1927. Five years later, when Lemaître shared his ideas during a seminar at Caltech, Einstein applauded: "This is the most beautiful and satisfactory explanation of creation to which I have ever listened." ARCHIVES LEMAÎTRE/UCL

velocity of extragalactic nebulae," was published April 25, 1927, in the *Annals of the Scientific Society of Brussels*. In it, Lemaître showed how Einstein's equations provided the physical basis for a non-static universe. This idea itself was revolutionary but, more importantly, Lemaître linked it to cutting-edge research.

In 1914, Vesto Slipher at Lowell Observatory found that distant galaxies show redshifts —spectra displaced toward the red — and are thus moving away from us. Lemaître believed this was evidence the universe is expanding, as his calculations affirmed. Using his non-static universe theory and the latest measurements, Lemaître derived a relationship between a galaxy's distance and its recession speed.

Modern astronomers recognize this as Hubble's law — but Lemaître anticipated it by 2 years. "This was the connection between theory and phenomena that set cosmology on the road to a mature physical science," writes Princeton University cosmologist P. J. E. Peebles in his book, *Principles of Physical Cosmology*.

In October 1927, Lemaître met Einstein at the Fifth Solvay International Conference in Brussels. As the priest related his ideas, Einstein sighed and told him a Russian, Alexander Friedman, had also concluded the universe was not static in 1922. But physicists of the time accepted the universe as ageless and unchanging. Einstein had even modified his equations with a repulsive force he called the cosmological constant to balance any expansion or contraction and maintain a stable, static universe. Einstein ended the meeting by saying, "Your calculations are correct, but your grasp of physics is abominable."

As a pure theorist, Friedman was unconcerned how his mathematics matched astronomical data. But Lemaître, who was now a part of the astronomical community, worked with the best data available and used them to refine his ideas, many of which had observable consequences astronomers could test. Lemaître had pushed things much further than had Friedman.

> "THE NOTION of a beginning … is repugnant." — *Arthur Eddington*

When Hubble published the 1929 paper giving a distance-velocity relation for galaxies, he cited Friedman's work but forgot the Belgian priest's — even though they had met many times. Hubble himself did not believe in an expanding universe. To him, redshifts always remained the motion of galaxies, not the signature of expanding space.

Primeval atom

In 1930, astronomers and cosmologists were at odds. Observations supported an expanding universe, while theorists predicted a static cosmos. Eddington announced in the journal *The Observatory* that he had begun a quest to find dynamical models able to explain the universe astronomers saw. Lemaître read this statement and wrote Eddington that he had solved the problem 3 years ago.

Eddington was impressed and decided to promote the work of his former student. He published a translation of Lemaître's 1927 article in *The Monthly Notices of the Royal Astronomical Society*. Unfortunately, Eddington left out an important section — the one expressing Hubble's law.

Although scientists eventually accepted cosmic expansion, its logical consequence was harder to swallow. In 1931, Eddington himself wrote that "Philosophically, the notion of a beginning to the present order of Nature is repugnant."

Lemaître did not share Eddington's aversion. Writing in *Nature* May 9, 1931, he claimed the question of a beginning could, in fact, be investigated physically. Of course, he offered the solution: "At the origin, all mass of the universe would exist in the form of a unique atom."

He imagined all the matter and energy in the universe compressed into a single, compact particle, and it was the disintegration of this "primeval atom" that gave birth to our universe. He recognized that space and time could have no meaning until this atom began expanding. The cosmos was born, he argued, on "a day without yesterday."

Lemaître wondered if there might be some observable consequence of his primeval atom's decay. He speculated that cosmic rays — nuclei traveling through space at high speed, discovered in 1912 — might be a trace remnant. The rest of the matter, though, ended up in stars and planets.

Cosmological constant

In 1933, Lemaître became the first to investigate how cosmic structures form in an expanding universe. He also derived fundamental results concerning what we

now call black holes; much later, others — notably Stephen Hawking — picked up on this work. In 1934, Lemaître was rightly considered the leader of the new cosmological physics, and Belgium awarded the priest the Francqui Prize, its highest scientific award.

Lemaître had always favored an accelerating universe, but his first models expanded so fast, there was simply no time to form stars and planets. The year he won the Francqui Prize, Lemaître reintroduced the cosmological constant. With the discovery of the expanding universe, Einstein had abandoned this "fudge factor." But Lemaître found the constant enabled him to develop a "hesitant" universe model in which the primeval atom's expansion initially decelerates. In time it reaches a plateau, after which the expansion speeds up.

Lemaître's preference for an accelerating universe was ahead of its time. In 1998, studies of distant supernovae found that the universe's expansion is accelerating.

Many scientists now suspect the cosmological constant apparently driving this acceleration derives from the vacuum energy of quantum physics. But the idea wasn't popular in the 1930s, especially with Einstein. He already had accepted the cosmological constant as the greatest mistake of his life and didn't want to revisit it.

In 1950, English astrophysicist Fred Hoyle, who backed a steady-state cosmic model, gave Lemaître's creation scenario the name with which we're most familiar. On his BBC radio program, Hoyle disdainfully referred to "this 'big bang' idea." The nickname not only stuck — it helped popularize the theory. Three years later, the Royal Astronomical Society awarded Lemaître the first of its Eddington Medals.

The two ways

Scientists were uncomfortable with a cosmic origin story because it appeared so close to Christian dogma — and, on top of that, a priest had proposed it. This may explain Lemaître's relative isolation in the scientific world.

EINSTEIN AND LEMAÎTRE found common ground at a 1933 Caltech seminar. Lemaître later studied an accelerating universe using Einstein's abandoned cosmological constant. ARCHIVES LEMAÎTRE/UCL

However, Lemaître successfully separated his scientific and religious lives.

He often asserted: "The supreme being cannot be reduced to a scientific hypothesis."

In November 1951, Pope Pius XII opened a Vatican conference with a discussion that linked Lemaître's primeval atom theory with the theological creation. Lemaître stepped in to prevent the pope from continuing to make this association. In 1960, as president of the Pontifical Academy of Sciences, Lemaître made sure everyone respected the autonomy of each of what he called "the two ways."

In June 1966, a heart attack forced Lemaître into a hospital, where he died later that month. But before his death, one of his assistants told the ailing priest about two American scientists, Arno Penzias and Robert Wilson, who had discovered faint microwave radiation all over the sky the year before.

This cosmic microwave background was the signature of the young universe's hot state. It was an observable trace of the primeval atom Lemaître had imagined nearly 40 years before.

LEMAÎTRE'S MODEL came to readers of *Popular Science Monthly* in 1932 thanks to this article by Donald Menzel of the Harvard College Observatory. Discussing the universe's future, Menzel writes that "Dr. Lemaître … prefers to believe that the whole universe … will keep expanding until the showering sparks which form the stars have burned to cinders and ashes." Modern cosmologists still can't say if this is true, but today's accelerating expansion suggests Lemaître may be right again. *POPULAR SCIENCE*

ONLINE EXTRA Learn about Lemaître's penchant for crunching numbers at www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

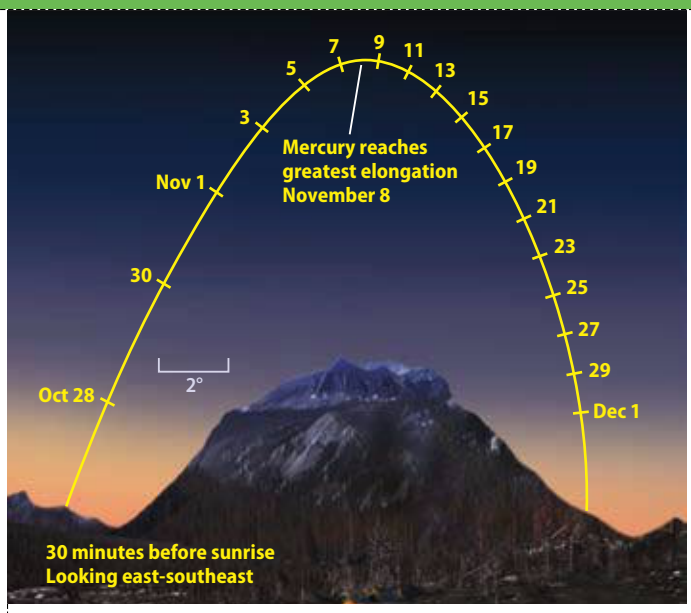
NOVEMBER 07

Mercury's great display before dawn

All five naked-eye planets — Mercury, Venus, Mars, Jupiter, and Saturn — put on nice shows these November nights. Mars dominates the late-evening sky as the planet prepares for opposition and peak visibility next month. It comes into view an hour or two after Jupiter slides gracefully into twilight. Mercury, Venus, and Saturn spread across the eastern sky before dawn.

44 Mercury nice before dawn
44 The Moon joins Venus
49 Catch the Leonid meteors
49 The Moon's Mare Australe
50 Twilight of a comet
51 Ceres at its best
51 The Red Planet returns

Visible to the naked eye
Visible with binoculars
Visible with a telescope



WATCH FOR MERCURY before dawn as the innermost planet puts on its best morning show of 2007. *ASTRONOMY*: ROEN KELLY

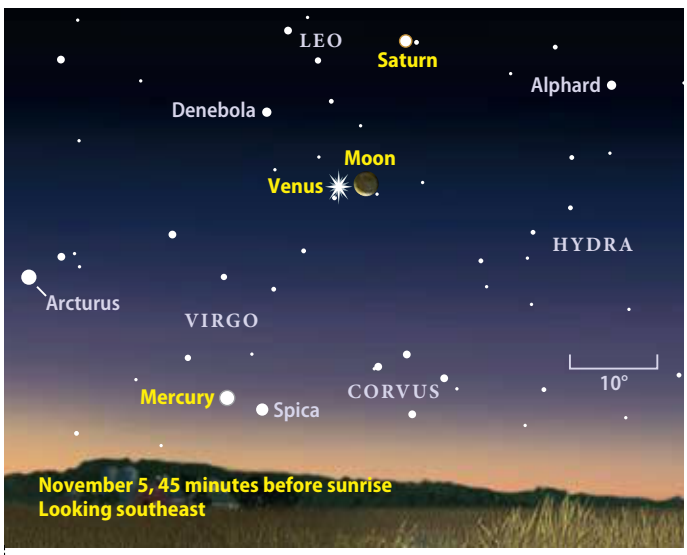
The two outer gas giants, Uranus and Neptune, remain easy binocular targets.

Jupiter spends November among the background stars of Ophiuchus the Serpent-bearer — the thirteenth constellation of the zodiac. The planet moves slowly eastward throughout November, ending the month at Ophiuchus' eastern border just as the Sun enters the constellation from the west. The Sun will remain in Ophiuchus for the first half of December, while Jupiter crosses into Sagittarius.

You can find Jupiter low in the southwest after sunset. Gleaming at magnitude –1.8, it easily shines through the twilight glow. However, its low altitude means our turbulent atmosphere will prevent sharp views of the planet's cloud features through a telescope. Still, you'll have no trouble spying its four bright moons. Look for a slender, 3-day-old crescent Moon standing 5° to Jupiter's lower left November 12. By month's end, Jupiter sets just an hour after the Sun.

Both Uranus and Neptune lie in the southern sky after sunset. **Neptune** appears farther west, situated among the faint stars of Capricornus. Binoculars will show it in the same field of view as Iota (ι) Capricorni, a 4.3-magnitude star 2° southwest of the planet. Neptune, at 8th magnitude, lies a

— *continued on page 49*

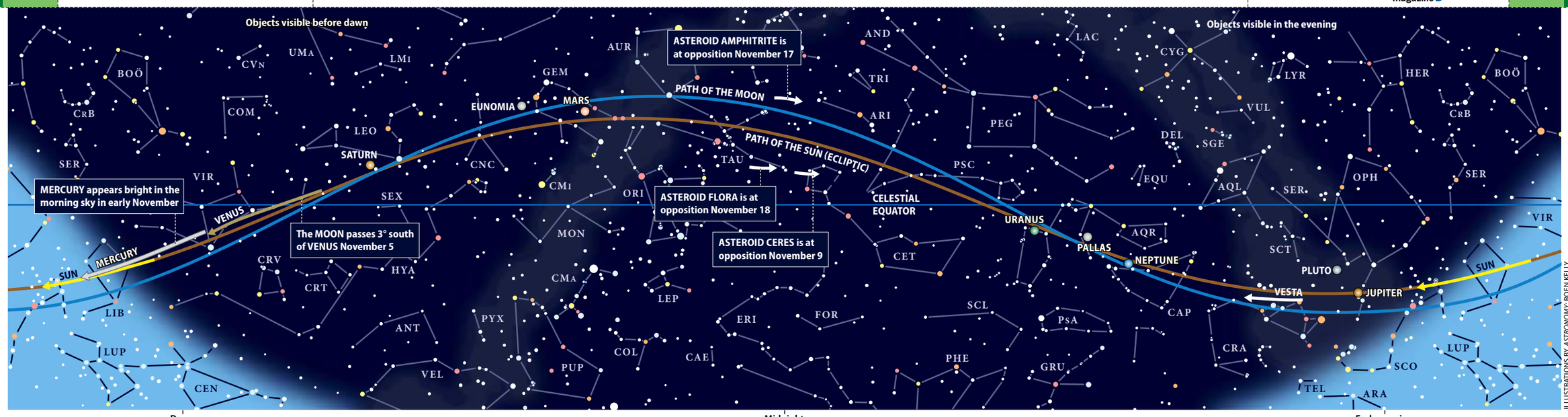


THE MOON PASSES VENUS before dawn November 5. The lunar crescent paired with the sky's brightest point of light will appear grand through binoculars or with the unaided eye. *ASTRONOMY*: ROEN KELLY

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine



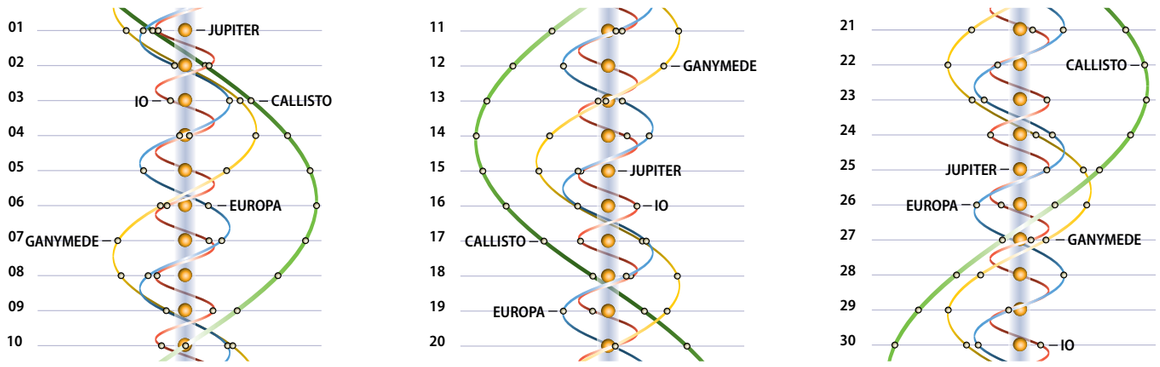
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

PLANETS	MERCURY	MERCURY	VENUS	MARS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	• PLUTO
Date	November 1	November 15	November 15	November 1	November 30	November 15	November 15	November 15	November 15	November 15
Magnitude	0.8	–0.7	–4.4	–0.6	–1.3	–1.8	0.8	5.8	7.9	14.0
Angular size	8.6"	5.9"	20.3"	12.2"	15.0"	32.3"	17.6"	3.6"	2.3"	0.1"
Illumination	22%	78%	59%	91%	97%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.786	1.142	0.822	0.770	0.624	6.095	9.465	19.694	30.078	32.170
Distance (AU) from Sun	0.308	0.359	0.719	1.508	1.545	5.264	9.254	20.095	30.044	31.372
Right ascension (2000.0)	13h28.5m	14h12.4m	12h26.4m	6h48.1m	6h47.8m	17h26.8m	10h38.5m	23h04.9m	21h26.8m	17h49.0m
Declination (2000.0)	–7°46'	–11°08'	–1°13'	23°57'	25°20'	–22°58'	10°11'	– 6°45'	–15°20'	–17°01'

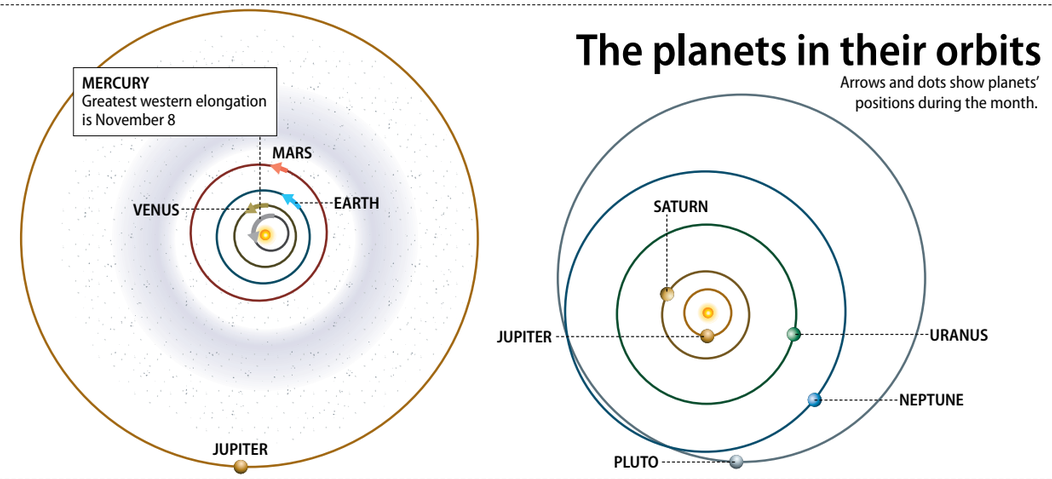
Jupiter's moons

Dots display positions of Galilean satellites at 8 P.M. EST on date shown. South is at top to match the view through a telescope.



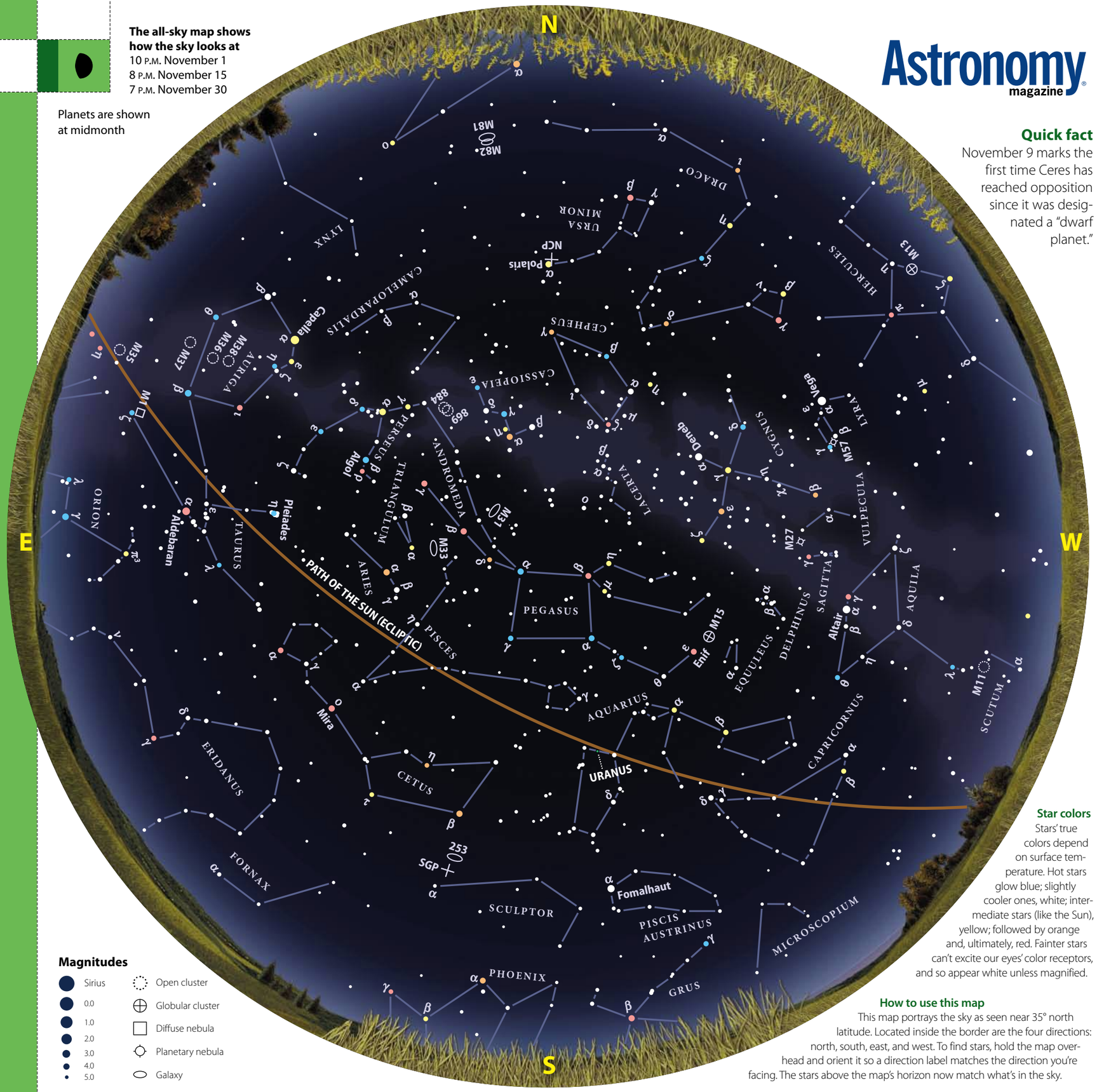
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
10 P.M. November 1
8 P.M. November 15
7 P.M. November 30

Planets are shown at midmonth



Magnitudes

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0
- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

Star colors
Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Astronomy magazine

Quick fact
November 9 marks the first time Ceres has reached opposition since it was designated a "dwarf planet."

NOTABLE OBSERVING DATE:
November 8, the peak of Mercury's best 2007 morning apparition.

november 07

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				[01]	[02]	[03]
[04]	[05]	[06]	[07]	[08]	[09]	[10]
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[25]	[26]	[27]	[28]	[29]	[30]	

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

01 Last Quarter Moon occurs at 5:18 P.M. EDT

03 The Moon passes 0.03° south of Regulus, 9 A.M. EDT

The Moon passes 1.8° south of Saturn, 11 P.M. EDT

05 The Moon passes 3° south of Venus, 3 P.M. EST

08 The Moon passes 7° south of Mercury, 6 A.M. EST

Mercury is at greatest western elongation (19°), 4 P.M. EST

09 The Moon is at apogee (252,694 miles from Earth), 7:32 A.M. EST

Asteroid Ceres is at opposition, 10 A.M. EST

New Moon occurs at 6:03 P.M. EST

11 The Moon passes 0.4° south of Antares, 4 P.M. EST

12 The Moon passes 5° south of Jupiter, 5 P.M. EST

17 Asteroid Amphitrite is at opposition, 8 A.M. EST

First Quarter Moon occurs at 5:33 P.M. EST

Leonid meteor shower peaks

18 Asteroid Flora is at opposition, 8 P.M. EST

23 The Moon is at perigee (221,950 miles from Earth), 7:13 P.M. EST

24 Full Moon occurs at 9:30 A.M. EST

27 The Moon passes 1.7° north of Mars, 1 A.M. EST

28 Venus passes 4° north of Spica, 5 P.M. EST

30 The Moon passes 0.3° south of Regulus, 3 P.M. EST

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

— *continued from page 44*

fraction of a degree from a star of equal brightness. The planet tracks slowly but noticeably eastward away from this star, creating the appearance of a quickly widening double star.

Uranus proves an easier target than Neptune. Swing your binoculars eastward to Phi (ϕ) Aquarii, a 4.2-magnitude star in eastern Aquarius. Phi lies some 20° due south of Markab, the star marking the southwestern corner of the Great Square of Pegasus. Uranus glows at magnitude 5.8 just 2.5° west of Phi. The 5th-magnitude double star 83 Aquarii lies 1° south of the planet. In early November, night-to-night observations will show the planet's westerly motion against the background stars. Uranus slows to a halt November 24, ending its retrograde loop.

Some 3 hours after the Sun goes down, brilliant **Mars** rises in the east. It nearly doubles in brightness during November, increasing from magnitude –0.6 to –1.3. Mars appears better during these next 3 months than at any time in the past 2 years, and it climbs as high as it ever reaches for Northern Hemisphere observers.

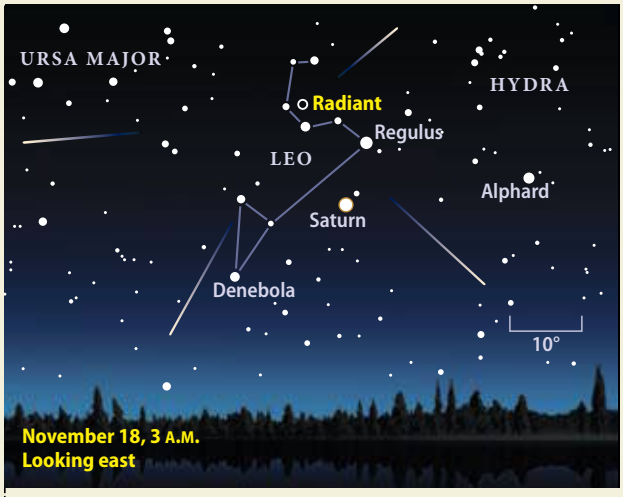
You'll find Mars in the constellation Gemini the Twins. The planet's orange-red color nicely matches that of the red supergiant Betelgeuse, which marks the shoulder of Orion's club-wielding arm. Mars and Betelgeuse have similar altitudes during the evening hours.

The Red Planet begins its retrograde loop November 15. This apparent westward motion against the distant stars, caused by Earth's orbital motion overtaking Mars, follows months of an eastward trek through Taurus and into Gemini.

On November 1, you'll find Mars southeast of Epsilon (ε) Geminorum, also known as Mebsuta. During the next 2 weeks, Mars moves east of the star and comes to a halt. During the month's second half, Mars' westerly pace picks up, and it swings back toward Mebsuta. On November 30, Mars lies just 0.8° from the 3rd-magnitude star. The westward motion signals the approach of opposition, which, in Mars' case, will come December 24.

Through a telescope, Mars' apparent size grows 25 percent during November, from 12" to 15". Careful observers also will notice the planet's slightly gibbous phase (91-percent lit) in early November. The disk waxes to nearly full by month's end.

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*



LEO THE LION hosts the Leonid meteor shower, which peaks this year in a moonless morning sky. *ASTRONOMY:* ROEN KELLY

LEO ROARS WITH BRIGHT METEORS

The Moon's absence makes this a good year for Leonid meteors. The shower peaks the morning of November 18, and the First Quarter Moon sets when the radiant rises, around midnight local time. Under a dark sky, meteor rates should range from 20 to 40 per hour once Leo climbs reasonably high after 3 A.M.

Although astronomers don't expect a major outburst, East Coast observers may see heightened activity before midnight November 17, when Earth crosses the orbital node of the Leonids' parent comet, 55P/Tempel-Tuttle.

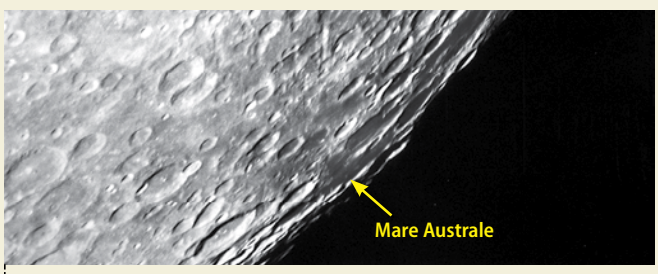
In the hour or two before dawn, Leonids strike Earth's atmosphere head on. This results in many bright events and some fireballs (meteors brighter than magnitude –4). Fireballs easily pierce twilight, so keep watch as the stars fade with dawn's approach.

THE FARSIDE ROLLS INTO VIEW

Pick up almost any book about observing, and you'll read that the Moon always keeps the same face pointed toward Earth. It's a nice story, but not totally true. This month, you can peer past 90° east longitude to see Mare Australe.

Because the Moon's orbit is elliptical and not perpendicular to its rotation axis, we see a slight side-to-side and up-down motion called libration during the course of a month. In mid-November, the Moon's southeastern limb tilts away from us, but it swings back into view by Full Moon the night of November 23/24.

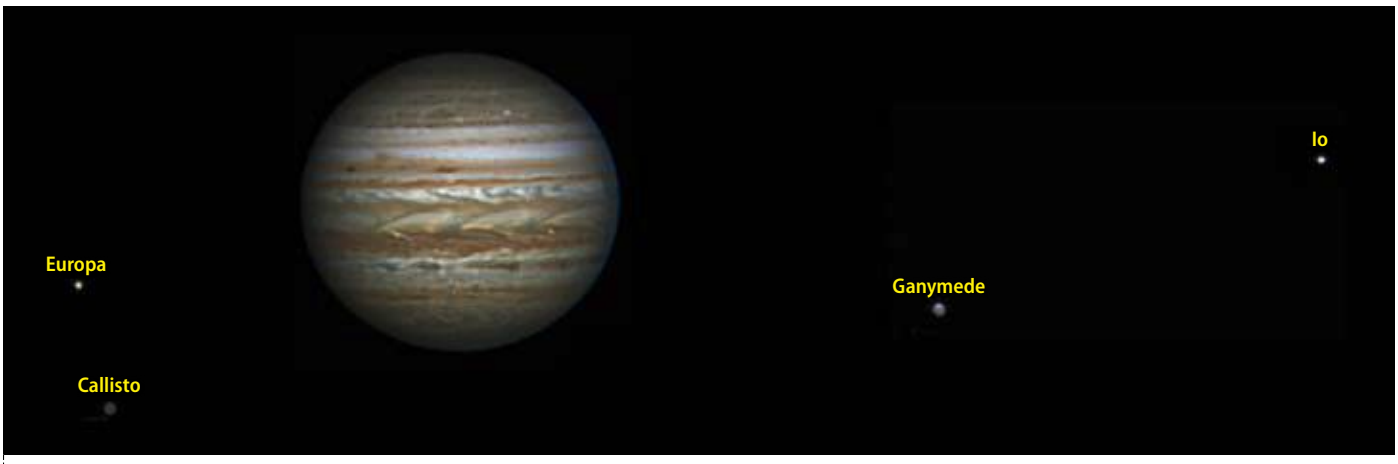
Concentrate on the Moon's southeastern limb. From the Northern Hemisphere at First Quarter phase (November 17), this region appears at lower right as we see the Moon with binoculars or the unaided eye.



MARE AUSTRALE normally stays out of sight, but it creeps into view around November's Full Moon. *CONSOLIDATED LUNAR ATLAS/UA/LPL*

The double-rayed splotch of bright surface material near the limb emanates from the craters Stevinus A and Furnerius A. The bright chip of Janssen K lies in the direction of the south pole. Notice how close these features are to the lunar limb.

Return each night to watch them move away from the edge. One week later, part of the huge, lava-filled impact basin called Mare Australe takes their place. It's pretty cool that in the space of a single week, a completely hidden lunar feature rolls into prominent view.



JUPITER AND ITS MOONS put on a final show in November's evening sky before disappearing in the Sun's glare. Although the planet's cloud bands will be hard to see, the four Galilean moons should stand out. MIKE SALWAY

Under good seeing conditions, patient observers should see surface features on the Red Planet. Wait until Mars climbs above 30° altitude, shortly before midnight. At first glance, the planet appears to be a bright orange ball. Give your eyes a few minutes to become accustomed to the view, however, and subtle bright and dark markings will begin to show.

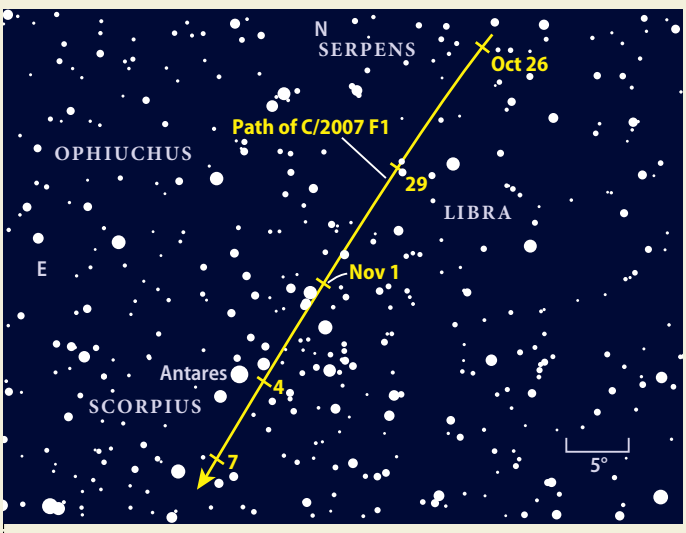
Neither pole tilts strongly toward Earth, but the planet's northern hemisphere is in the last few weeks of its winter, so the north polar cap should appear more prominent.

Around local midnight in early November, Mars shows the region called Solis Lacus ("Eye of Mars") to North American observers. Later in the month (or later in the night), Syrtis Major swings into view. Mars completes one rotation every 24 hours and 37 minutes, so observers at different longitudes will see different hemispheres of Mars.

By the end of November, **Saturn** rises a little before midnight (it's up by 2 A.M. in early November). The ringed planet shines at magnitude 0.8 among the stars of Leo. Saturn now lies 8° east of the constellation's brightest star, 1st-magnitude Regulus, but will return to the star's vicinity next May.

Through a telescope, the spectacular rings span a healthy 40" this month. Notice that the rings tilt noticeably less to our line of sight than they did earlier this year. On November 30, Saturn reaches quadrature, when the angle between the Sun and Saturn is 90°. At this time, the shadow of the planet's globe appears most conspicuous on the rings behind. This shadow gives Saturn a dramatic three-dimensional look.

Saturn's moons make nightly appearances. The brightest,



COMET C/2007 F1 (LONEOS) appears low in the southwest after sunset in early November. This will be the last chance to see this comet before it returns to the outer solar system. *ASTRONOMY:* ROEN KELLY

CATCH THIS BINOCULAR BEAUTY

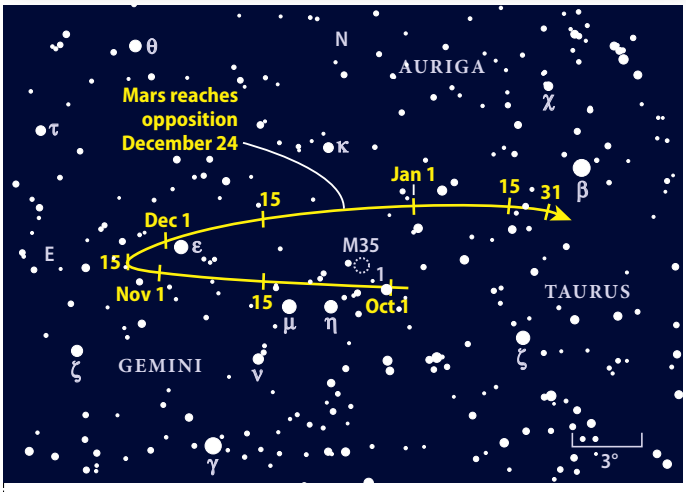
As twilight deepens in late October and early November, use binoculars to scan above the Sun's remnant glow for Comet C/2007 F1 (LONEOS). This 6th-magnitude visitor should sport a decent tail angling from the southwestern horizon up toward Jupiter. Catch it early — the view deteriorates rapidly after November's first week as the comet heads back to the outer solar system.

You'll need a telescope to see delicate features in the comet's two tails. The dust tail usually appears brightest. Its glow comes from sunlight scattering off dust lifted off the comet's nucleus by jets of sublimating ice. This yellowish fountain curves gradually toward the north as the dust particles assume their own orbital paths around the Sun.

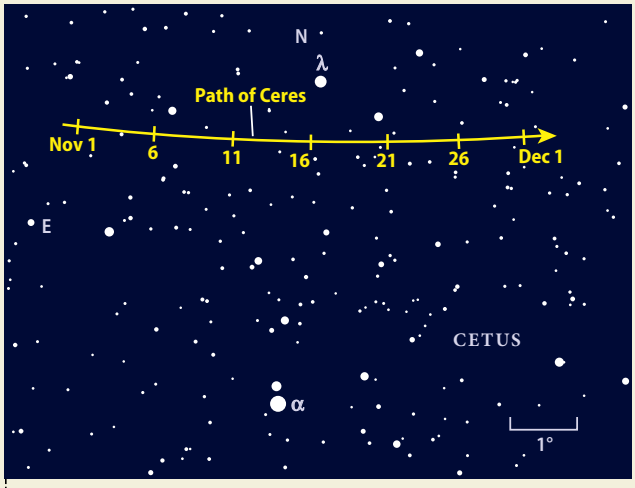
On the comet's southeastern flank (left as seen from the Northern Hemisphere), a sharp streak heads straight away from the Sun. This is the ion tail, a collection of molecules ionized by the Sun's ultraviolet radiation and carried away by charged particles in the solar wind. The ion tail glows blue, although you shouldn't expect to see color unless the tail is particularly bright or you have a large scope.

/// WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Jupiter (southwest)	Mars (east)	Mercury (east)
Uranus (south)	Uranus (west)	Venus (southeast)
		Mars (west)
		Saturn (southeast)



MARS BACKS UP in November as it begins retrograde (westward) motion in Gemini. With just a month to go before opposition, the Red Planet shines brightly from late evening on. *ASTRONOMY:* ROEN KELLY



DWARF-PLANET CERES peaks this month as it reaches opposition. The asteroid glows at 7th magnitude in Cetus, where it will be easy to pick out with binoculars. *ASTRONOMY:* ROEN KELLY

DESPERATELY SEEKING CERES

With a little effort this month, you can trace part of an asteroid's retrograde loop. Simply grab your binoculars and step into the backyard for a few minutes every couple of nights. Asteroid 1 Ceres, the biggest object in the main belt between Mars and Jupiter, glows at magnitude 7.2 at opposition November 9.

Ceres floats in front of the sparse star field in the tail of Cetus the Whale, which lies due south around local midnight. The asteroid appears brighter than all but a handful of stars, making it easy to follow through binoculars on a night-by-night basis.

Place the bright star Alpha (α) Ceti at the field's bottom, then look to the top. Use the chart above to identify surrounding stars and hone in on Ceres. With a diameter of nearly 600 miles, the asteroid has enough gravity to shape itself into a sphere. That's why the International Astronomical Union last year raised Ceres' status to "dwarf planet," one step below planethood. Two centuries ago, astronomers classified Ceres as a planet before they recognized it as the largest of many objects with similar orbits.

Sicilian astronomer Giuseppe Piazzi discovered Ceres January 1, 1801, when he noticed a "star" unaccounted for in catalogs. Like Mars, Ceres has a somewhat elliptical orbit, although the asteroid takes more than twice as long as Mars — 4.6 years — to complete a solar circuit.

8th-magnitude Titan, shows up easily in small scopes. You can spot it north of Saturn November 3 and 19, and south of the planet November 11 and 27.

Two-faced Iapetus spends much of its time far east or west of Saturn. On November 23, however, it passes due north, and will show up as an 11th-magnitude dot. The moon then moves west of the planet, which turns its brighter hemisphere in our direction. By mid-December, Iapetus will brighten to magnitude 10.1.

In early November, brilliant **Venus** rises an hour and a half after Saturn and a whopping 4 hours before the Sun. On the 4th, a crescent Moon lies between Saturn and Venus. One night later, the waning Moon passes 3° to Venus' right.

The two planets move apart during the month because Venus follows the Sun eastward while Saturn's angular separation from the Sun increases. On November 1, they lie 16° apart; by the 30th, 46° separate them.

Venus crosses two-thirds the width of Virgo during November. On the 5th, it passes half the Moon's width north of Beta (β) Virginis. On the 13th, Venus comes within 0.1° of Eta (η) Vir, and 5 nights after that, it's 1° south of Porrima (Gamma [γ] Vir). Venus' nightly progression continues, bringing it 4° north of the constellation's brightest star, Spica, November 28.

Venus easily outshines all of Virgo's stars — outpacing 1st-magnitude Spica by 100 times. The brilliant planet does dim slightly during November, however, from magnitude –4.5 to –4.3. Through a telescope, Venus' disk shrinks from 23" to 18" across, while its phase waxes from 52-percent to 65-percent illuminated.

Mercury puts on its best predawn show of the year this month for Northern Hemisphere observers. On the 3rd, it rises about 90 minutes before the Sun and stands 4° north of Spica. The planet outshines Spica by a full magnitude. A crescent Moon lies 9° to Mercury's right November 7, forming a nice trio with Spica.

The inner planet reaches the peak of its current apparition at greatest western elongation on the 8th. It then shines at magnitude –0.6 and lies 9° high in the east 45 minutes before sunrise. By the 21st, it passes three Moon-widths north of Alpha (α) Librae, also known as Zubenelgenubi. After that, Mercury sinks rapidly toward the Sun. The planet disappears from view by month's end.

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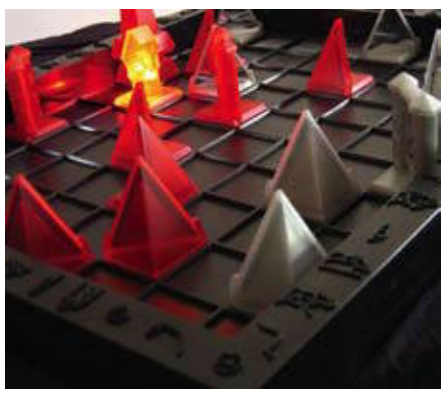

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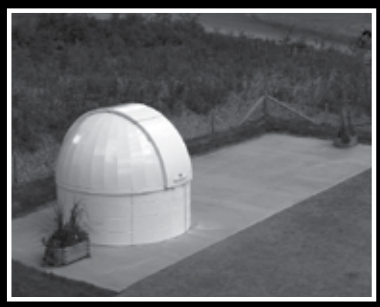

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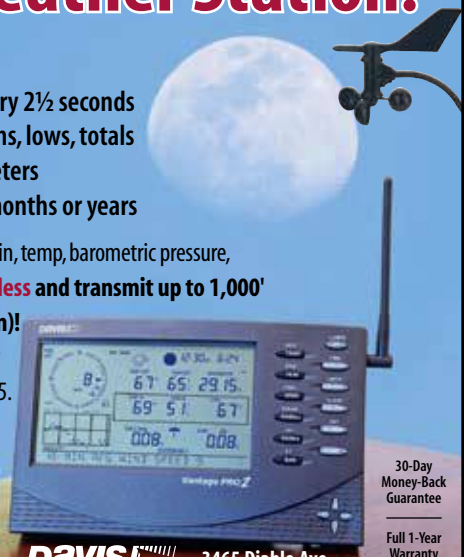

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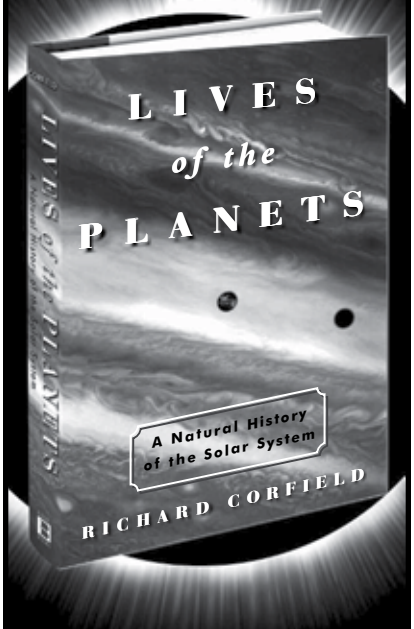

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Making sense of galaxies

Astronomers' efforts to explain galaxy types brought them from a tuning fork to a lemon.

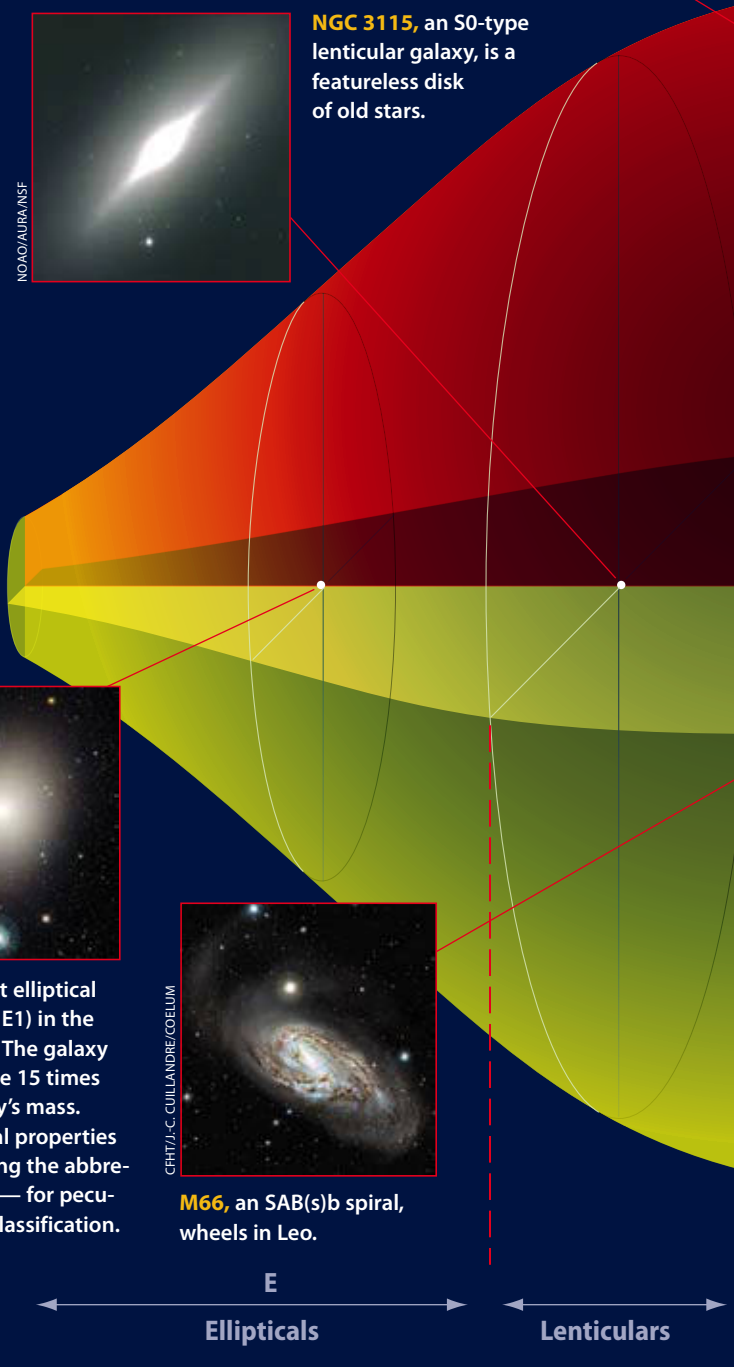
/// BY FRANCIS REDDY; ILLUSTRATION BY KELLIE JAEGER

Astronomers have struggled to classify galaxies since the 1920s, when Edwin Hubble at California's Mount Wilson Observatory first proved they were "island universes" beyond our Milky Way. Hubble found he could lump most galaxies into a few broad types — elliptical, normal spiral, and barred spiral — and he placed them into a tuning-fork-shaped sequence.

Galaxies display a huge range of sizes and masses — from nearby dwarfs that contain fewer stars than a globular cluster to mammoths like M87. Galaxies show a range of structures, too, including bulges, disks, bars, rings, and spiral arms.

The subtler details of galactic structure required a more nuanced scheme than Hubble's. In the late 1950s, Gérard de Vaucouleurs devised a 3-D version of the tuning fork — shown here — based on observations of a few hundred southern galaxies.

But distant galaxies, seen when the universe was younger, smaller, and more crowded, don't fit into the scheme. Moreover, new surveys of tens of thousands of galaxies suggest they occupy two distinct zones when plotted by color and brightness. No one yet knows how to reconcile such observations with the smooth variations astronomers see among different galaxy types.



GIVING HUBBLE'S tuning fork a half twist creates the lemon-shaped "classification volume" Gérard de Vaucouleurs developed in the late 1950s. Normal galaxies occupy the top half, barred galaxies go on the bottom. Different galaxy types occur left to right. Codes describe each galaxy based on its position within the volume. The "lemon's" height reflects the relative number of each galaxy type found in the sample.

NASA/ESA/S. BECKWITH (STScI) AND THE HUDF TEAM

LOOKING BACK in time using the Hubble Space Telescope, astronomers see young, ragged galaxies unlike any seen nearby today. These galaxies are colliding with each other.

CFHT/J.-C. CUILLANDRE/COELUM

M87 is a giant elliptical galaxy (E0 or E1) in the Virgo cluster. The galaxy contains some 15 times the Milky Way's mass. M87's unusual properties warrant adding the abbreviation "pec" — for peculiar — to its classification.

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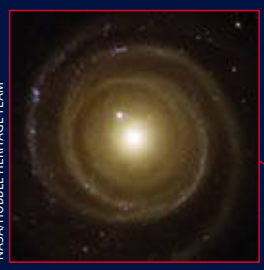
M66, an SAB(s)b spiral, wheels in Leo.

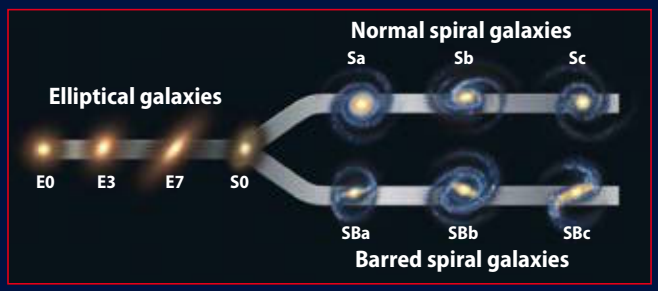


NASA/HUBBLE HERITAGE TEAM

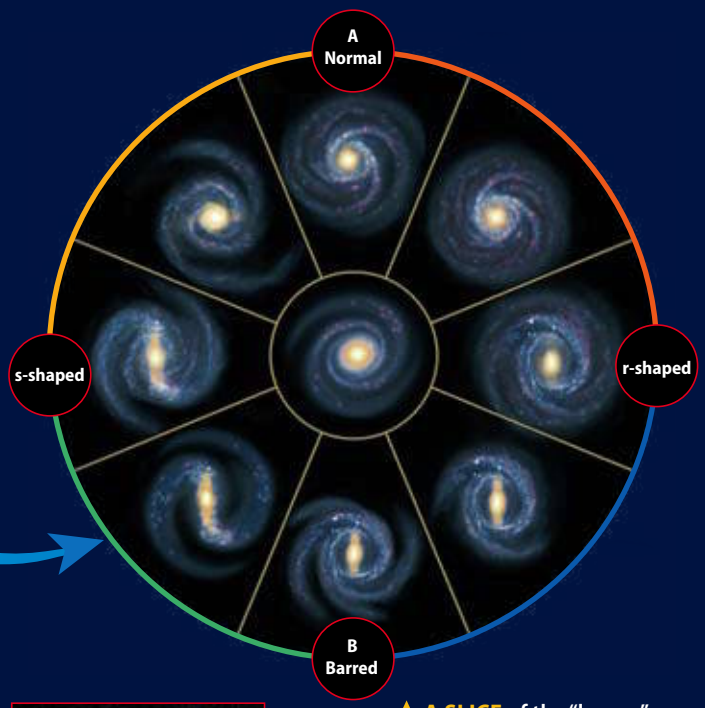
NGC 4622, a face-on spiral galaxy in Centaurus, is classed as SA(r)ab.

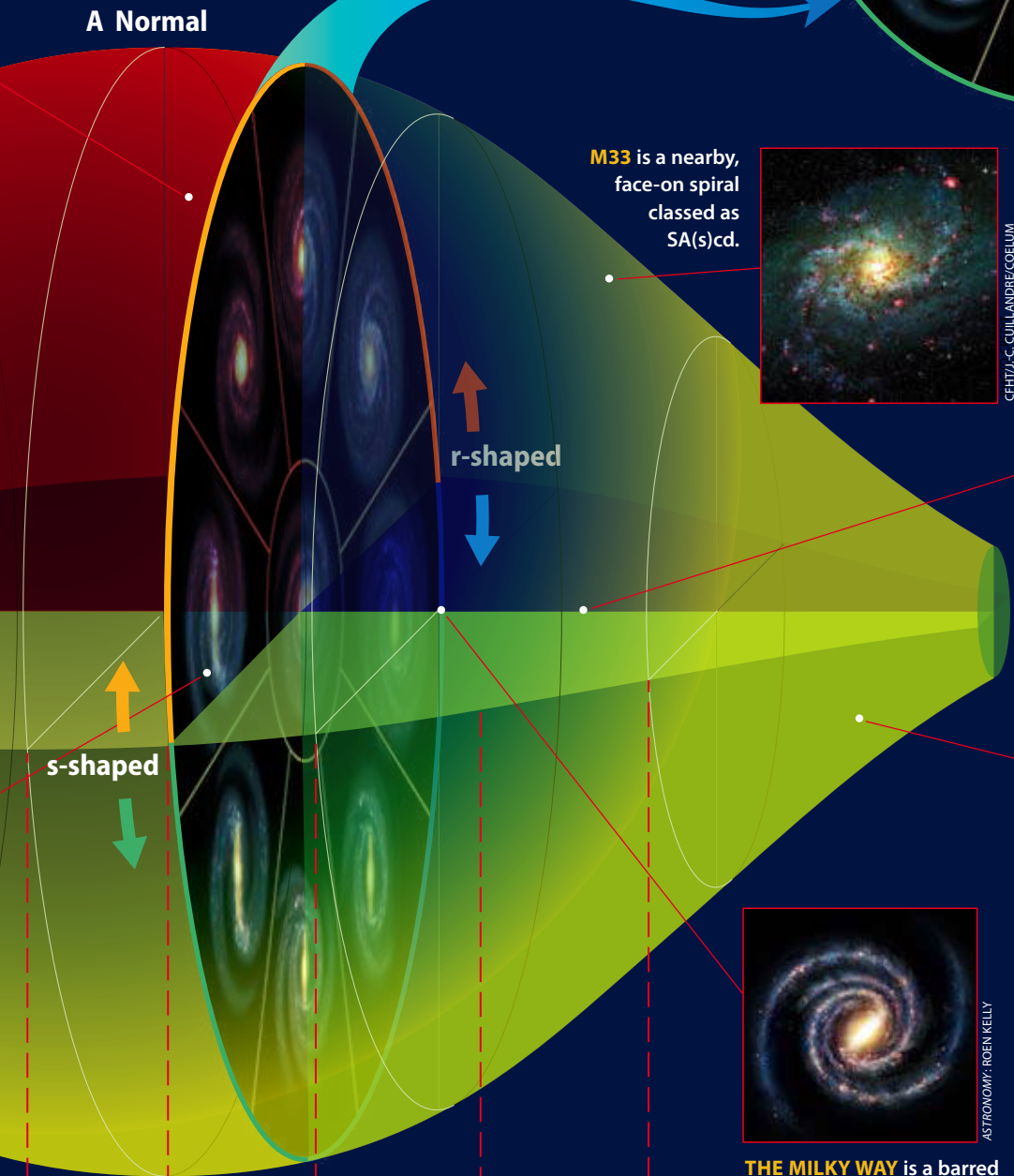
NOAO/AURA/NSF

NGC 3115, an S0-type lenticular galaxy, is a featureless disk of old stars.



IN 1926, Edwin Hubble devised his "tuning fork" scheme for classifying galaxies. Ellipticals, rich in old stars but with little gas to make new ones, give way to lens-shaped lenticulars and gas-rich normal and barred spirals. Irregular galaxies form a separate catch-all category.





M33 is a nearby, face-on spiral classed as SA(s)cd.

CFHT/J.-C. CUILLANDRE/COELUM

▲ A SLICE of the "lemon" reveals a wheel of galaxy shapes based on the presence of a central stellar bar and the degree to which the galaxy's arms look spiral- (s) or ring- (r) shaped.

Relative number of galaxies

CFHT/J.-C. CUILLANDRE/COELUM

THE PINWHEEL GALAXY (M101), class SAB(rs)cd, shows clear and well organized spiral structure.

NOAO/LGGST

NGC 6822, an IBm-type dwarf galaxy, still has many star-forming regions.

ASTRONOMY: ROEN KELLY

THE MILKY WAY is a barred spiral, classed SAB(rs)bc.

Astronomy magazine

If your observing list doesn't contain variable stars, here's an easy guide to some of the finest. /// BY MICHAEL E. BAKICH

DON FIGER (STScI)/NASA

How to observe variable stars

"Change in all things is sweet," said Aristotle. In astronomy, objects called variable stars provide sweet views to observers. Variable stars are ones whose brightnesses change over time. One night, a star field might contain several dozen similarly bright stars. A week later, one star might shine brighter than the rest. Has it exploded? Probably not. More often, the star will fade and, after a period of time, brighten again. By knowing where to look, you can follow these changes through even a small telescope.

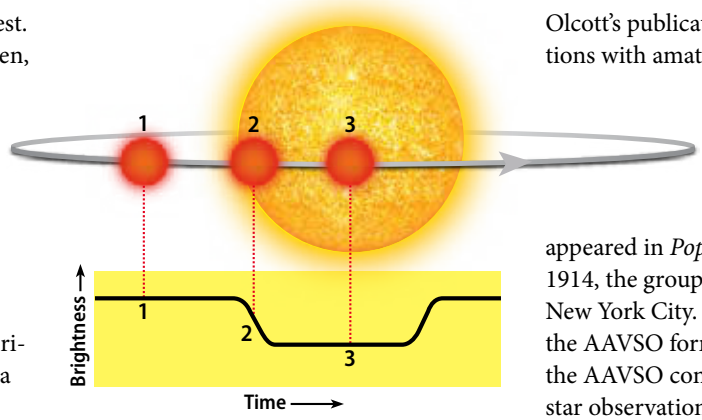
A variable history

If you don't count supernovae, the first variable star — and certainly the first periodic variable star — discovered was Mira (Omicron [o] Ceti), in 1596 by German astronomer David Fabricius (1564–1617). Mira's variability caused astronomers to think about stars in different ways. Before then, the universe seemed unchanging. Other variable-star discoveries followed. Italian astronomer Geminiano Montanari (1633–1687) noted the variability of Algol (Beta [β] Persei) in 1669. Dutch-born British astronomer John Goodricke (1764–1786) discovered Delta (δ) Cephei, the prototype for all Cepheid variables, in 1784. He also explained why Algol varies in brightness: It's a double-star system in which one star revolves around another — an eclipsing binary, the first to be found.

By the mid-19th century, astronomers had discovered so many variable stars that they didn't have the resources to follow them all. German astronomer Friedrich Wilhelm August Argelander (1799–1875) and American astronomer Benjamin Apthorp Gould (1824–1896) called upon amateurs worldwide to submit observations of variable stars. Gould gathered variable-star observations from amateur astronomers across the United States and published them in *The Astronomical Journal*, which he edited.

By the mid-1880s, Harvard College Observatory Director Edward C. Pickering (1846–1919) and, later, American astronomer William Tyler Olcott (1873–1936) began providing variable-star observers with charts that had the variable and nearby comparison stars marked directly on them. Twenty-five years later, Pickering began to enter the magnitudes of comparison stars directly on the charts.

In December 1911, spurred on by Olcott's publications and his communications with amateur astronomers, the first observations of the group that would become the American Association of Variable Star Observers (AAVSO) appeared in *Popular Astronomy*. In April 1914, the group held its first meeting in New York City. Finally, in October 1918, the AAVSO formally incorporated. Today, the AAVSO continues to support variable-star observations. Check out the group's web site at www.aavso.org.



A LIGHT CURVE is the tool astronomers use to plot a variable star's brightness over time. Observers record many measurements, and software determines the curve that best fits the data. *ASTRONOMY:* ROEN KELLY

Labeling variables

In 1862, Argelander assigned the uppercase Roman letters R through Z to variable stars within a constellation. After he ran through these nine letters, Argelander used double uppercase letters (RR–RZ, SS–SZ ... AA–AZ, BB–BZ ... QQ–QZ).

Because Argelander did not use the letter J to begin these pairs, he was able to denote a total of 334 stars in this fashion. So, R CrB is the first variable star in Corona Borealis and QZ Ori is the 334th variable star in Orion. If a constellation requires even more designations (and many do), astronomers use a single uppercase V plus numbers after 334. Therefore, Plaskett's Star carries the designation of V640 Mon, the

— *Continued on page 59*

Michael E. Bakich *is a senior editor of* Astronomy.

Observe these variables

Two main types of variables exist: intrinsic and extrinsic, and each type has two classes. Pulsating variables and eruptive variables comprise the intrinsic type. The brightness of these two types varies because of inner physical changes.

Eclipsing binaries and rotational variables are the two classes within the extrinsic type. Eclipsing binaries drop in brightness when one star in the system eclipses the other. Rotating stars may expose different areas to us as they spin. A large number of sunspots on one side of the star can greatly affect its brightness.

Subclasses exist within the two variable-star classifications. Following is a list of the most familiar. Objects have their given names because astronomers label most variable-star types after the first star discovered in its class, known as the prototype. — *M. E. B.*

Algol type

Prototype:	Beta (β) Persei
Right ascension:	3h08m
Declination:	40°57'
Period:	2.87 days
Magnitude range:	2.1 to 3.4

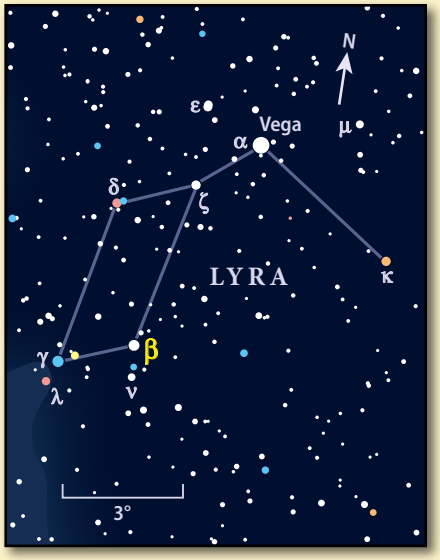
The classic eclipsing binary, Algol makes an easy target because you can see its brightness vary with your naked eyes. The two stars in the system are far enough apart that, most of the time, their combined light is constant. For observers, the best part happens when the light drops more than a magnitude in about 5 hours, waits 20 minutes, then begins to climb again.

You can compare Algol to other nearby stars such as Gamma (γ) Andromedae. At maximum, Algol shines just 0.15 magnitude brighter than Gamma. At minimum, it glows more than a magnitude fainter. Most Algol variables have periods of a few days.

Beta Lyrae type

Prototype:	Beta (β) Lyrae
Right ascension:	18h50m
Declination:	33°22'
Period:	12.91 days
Magnitude range:	3.3 to 4.4

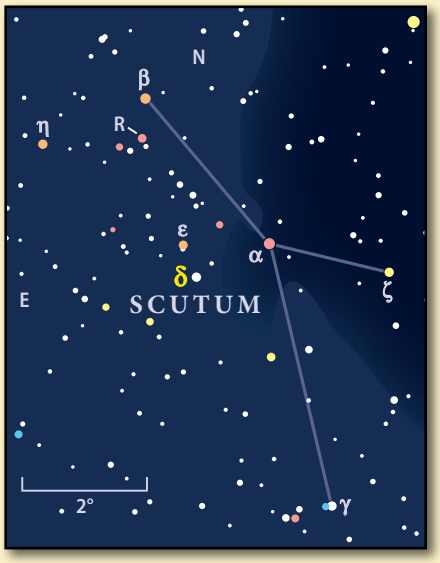
This system's stars are so close, they're either touching or nearly so. Their shapes are so distorted by gravity that — if we could see the individual stars — they'd look like eggs. At no point on their light curve is their light output steady. When observing the prototype, β Lyr, compare it to nearby magnitude 3.2 Gamma (γ) Lyrae, which lies 2° to the east-southeast. At brightest, Beta is equal to Gamma in brightness, but it glows a magnitude fainter than Gamma when dimmest.



Delta Scuti type

Prototype:	Delta (δ) Scuti
Right ascension:	18h42m
Declination:	–9°03'
Period:	4h 39m
Magnitude range:	4.6 to 4.8

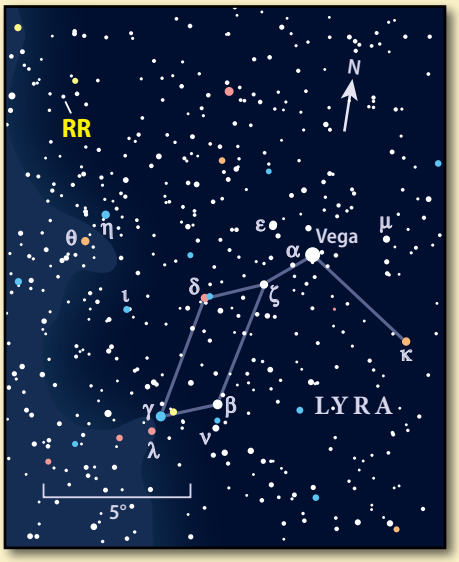
You may have difficulty seeing the variability in this class because most Delta Scuti stars change their brightnesses by less than 0.1 magnitude. So, start with some of the easier types of variables — like those of the Algol type — and later expand your list to include some Delta Scuti examples. If you own a digital or CCD camera, however, you'll find it easier to record this class of stars' variations.

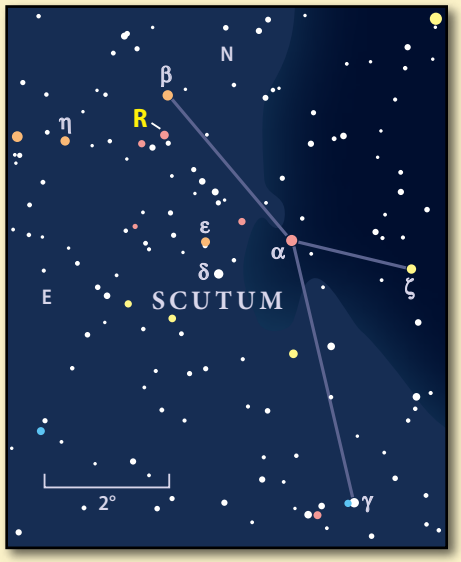


W Ursae Majoris type

Prototype:	W Ursae Majoris
Right ascension:	9h44m
Declination:	55°58'
Period:	4 hours
Magnitude range:	7.6 to 8.4

This type of variable star resembles the Beta Lyrae type. In both cases, contact binaries make up the systems. W UMa variables are cooler and less massive than Beta Lyrae variables. Because the stars are in contact, it's hard to tell precisely when eclipses begin and end.





Mira type

Prototype:	Omicron (o) Ceti
Right ascension:	2h19m
Declination:	–2°59'
Period:	333.8 days
Magnitude range:	2 to 10 (both vary)

Mira-type variables are red giants with periods of up to 3 years. Keeping track of this type of star can be rewarding, however, because the best examples have wide brightness ranges. Astronomers discovered many Mira-type variables after Fabricius found their prototype in 1596, and their designations (noted by the letter R) show that, in most northern constellations, a Mira-type variable was the first variable star seen. In addition to Mira, check out R Leonis, R Andromedae, R Leporis, and R Serpentis.

RR Lyrae type

Prototype:	RR Lyrae
Right ascension:	19h25m
Declination:	42°47'
Period:	13h 36m
Magnitude range:	7.1 to 8.1

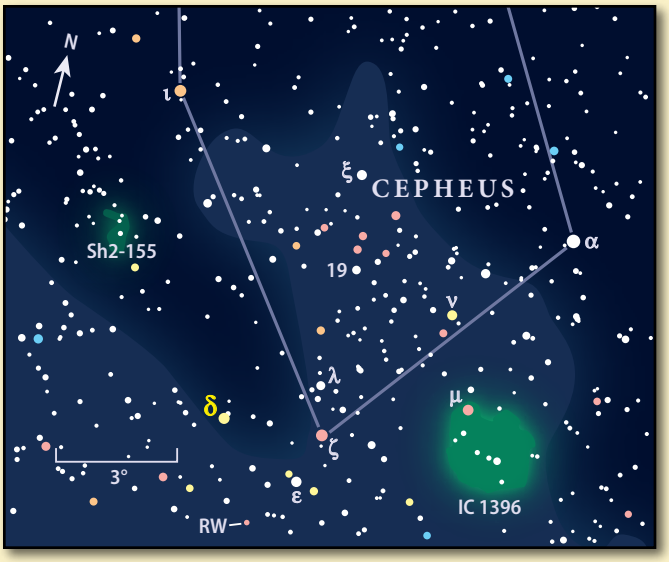
Stars in the RR Lyrae class all have roughly the same intrinsic brightness — around 60 times the Sun's luminosity. Because of this, these stars make good distance indicators, similar to Cepheids, although astronomers can detect Cepheids at much greater distances. Astronomers find many RR Lyrae stars in globular clusters. Try to observe the prototype's cycle in one night. Depending on your location (and the time of year), you'll see either the full range of variability or nearly all of it.

RV Tauri type

Prototype:	R Scuti
Right ascension:	18h47m
Declination:	–5°42'
Period:	140 days
Magnitude range:	4.5 to 8.2

Although the class is RV Tauri, the prototype is R Scuti, a star discovered to be variable in 1795. Stars of RV Tau type are luminous yellow giants. The brightness minimum, slightly below 8th magnitude, has two separate levels, alternating between a shallow minimum and a deep one.

Astronomers define the period of an RV Tau star as the length of time between two of its deep minima. The brightness of the prototype — even at minimum — places it well within the reach of any telescope.

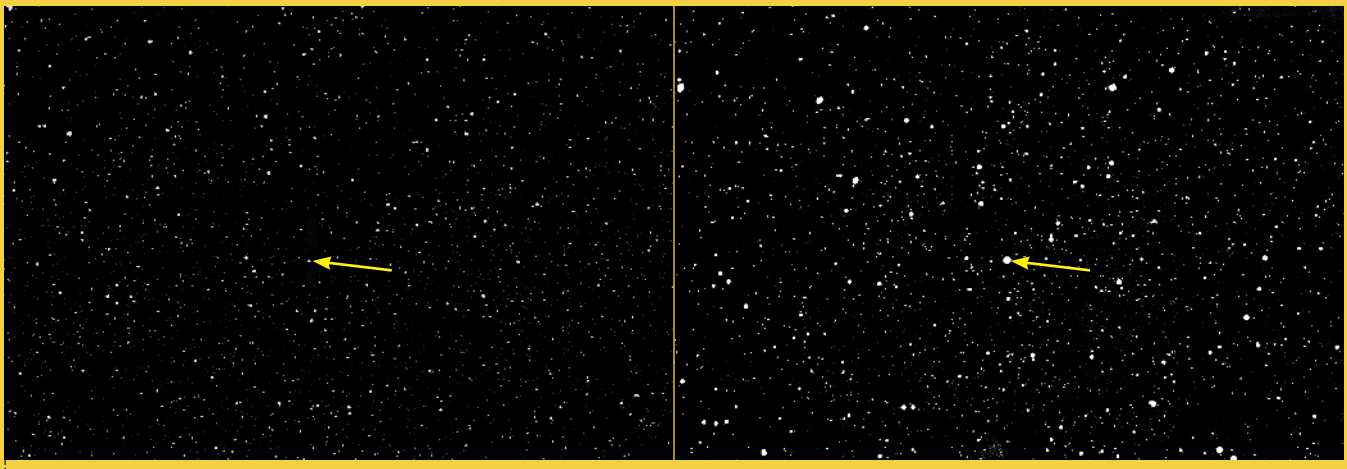


Delta Cepheid type

Prototype:	Delta (δ) Cephei
Right ascension:	22h29m
Declination:	58°24'
Period:	5.37 days
Magnitude range:	3.5 to 4.4

The "measuring stick" of astronomy, Delta Cepheids (usually shortened to Cepheids) have an amazing characteristic: Their periods relate directly to their luminosities. So, once astronomers measure a Cepheid's period, they can calculate its absolute magnitude (how bright it would look from a standard distance of 32.6 light-years). Comparing that quantity with the star's apparent magnitude (how bright it appears) reveals its distance.

Cepheids are young stars of several solar-masses and about 10,000 times the Sun's luminosity. Cepheids pulsate because helium in the stars' outer layers ionizes, which makes it opaque. As it darkens, the gas absorbs more energy, the star expands, and its brightness increases. As it expands the helium cools, causing the star to shrink. ALL CHARTS: *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY



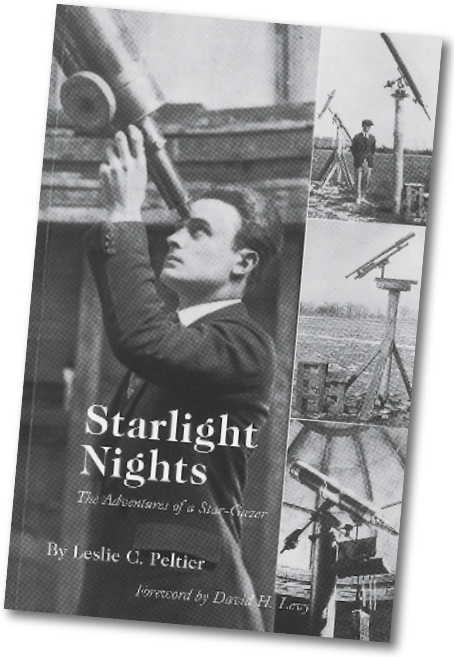
MIRA (Omicron [o] Ceti), has a period of nearly 334 days. During that time, it increases in brightness from about 9th magnitude to as bright as 2nd magnitude and then dips back. At minimum, Mira disappears from naked-eye visibility. JOHN SANFORD

— *Continued from page 56*

640th variable star in the constellation Monoceros the Unicorn.

Novae initially carry constellation and year designations, like Nova Cygni 1975. When the event's brightness diminishes, such objects receive a variable-star designation. So, for example, astronomers now refer to Nova Cygni 1975 as V1500 Cyg.

The AAVSO also employs a numerical system for variable stars. By this numbering, R Leporis has the additional AAVSO designation of 0455–14. These numbers represent the star's approximate right ascension (4h55m) and declination (–14°) for the year 1900.



FOR MORE ON the history of variable-star observing, read *Starlight Nights* by Leslie C. Peltier (Sky Publishing Co., Cambridge, Massachusetts, 1999). *ASTRONOMY:* WILLIAM ZUBACK

Recording changes

Seasoned observers telescopically compare target variable stars with nearby, similarly bright stars. Good estimates have an error of about 0.1 magnitude. If you're just starting out, however, you won't come close to this level of precision. That's OK. Sometimes, I like to check in on a few favorite variables just to say, "Wow! That's a lot brighter than it was 3 days ago." Or, if the star is near minimum brightness, it may appear to have vanished.

One solution in the quest for precision measurements is to take images of the target's star field with either a digital single-lens reflex (DSLR) or charge-coupled device (CCD) camera. With this technology, you can measure variable-star brightnesses to an accuracy astronomers could only dream about a century ago. Medium-sized telescopes equipped with CCD cameras typically detect 16th-magnitude stars. Add to such a system a computerized drive and software running a control script containing a night's list of variable stars, and the amount of data you can collect will amaze you — all while you're either looking through a different telescope or asleep.

Stars are point sources, and even relatively faint ones record quickly. Use a DSLR or CCD camera, experiment with exposure times, and discard any images you don't like. Once you settle on an exposure time, however, it's important that you use the same interval for each image of the variable throughout its entire period. Label each image with the date and time. If you take enough images throughout the variable's cycle, you can chart the star's light curve.

A light curve is a simple graphic astronomers use to plot a variable star's brightness over time. Each point on the curve represents the star's magnitude at a specific time. The more points used to make a light curve — and the smaller the intervals between them — the more accurate the curve will be. Once they've accumulated many points, astronomers use a mathematical formula to smooth out the points and generate a curve.

If you don't have a DSLR or CCD camera and you want to record your observations, use the tried-and-true method of sketching what you see through the eyepiece. Take care to portray different star brightnesses accurately, either by larger dots or by pressing lighter or harder with your pencil. As with images, label each sketch with the date and time.

For more than a century, amateur astronomers measured, recorded, and submitted reports of variable stars by visual observation and sketching. Much of what we know about the light curves of these stars has come from such observations. That era has passed, but it's still fun and challenging to set up a telescope and watch a star's brightness change.

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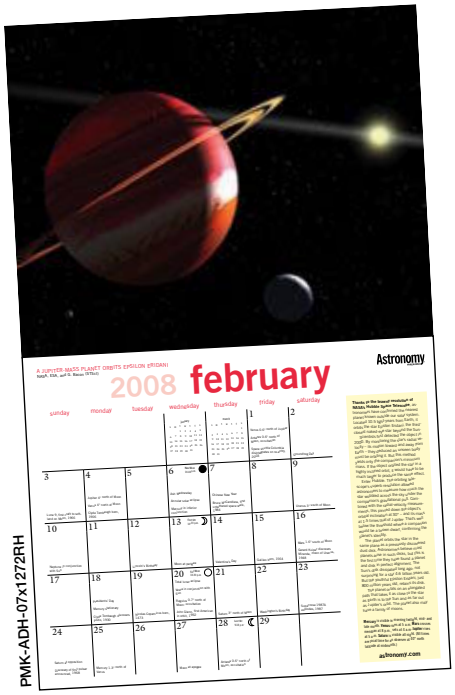

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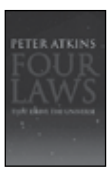

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ASK ASTRO

This month:
- Can you see the American flag astronauts placed on the Moon?
- Can Hubble see planets around other stars?
- Could an asteroid impact change Earth's climate?
- Can black holes stretch or rip space-time?
- How do you use *Astronomy*'s "Planets this month" foldout map?

MOON FLAG

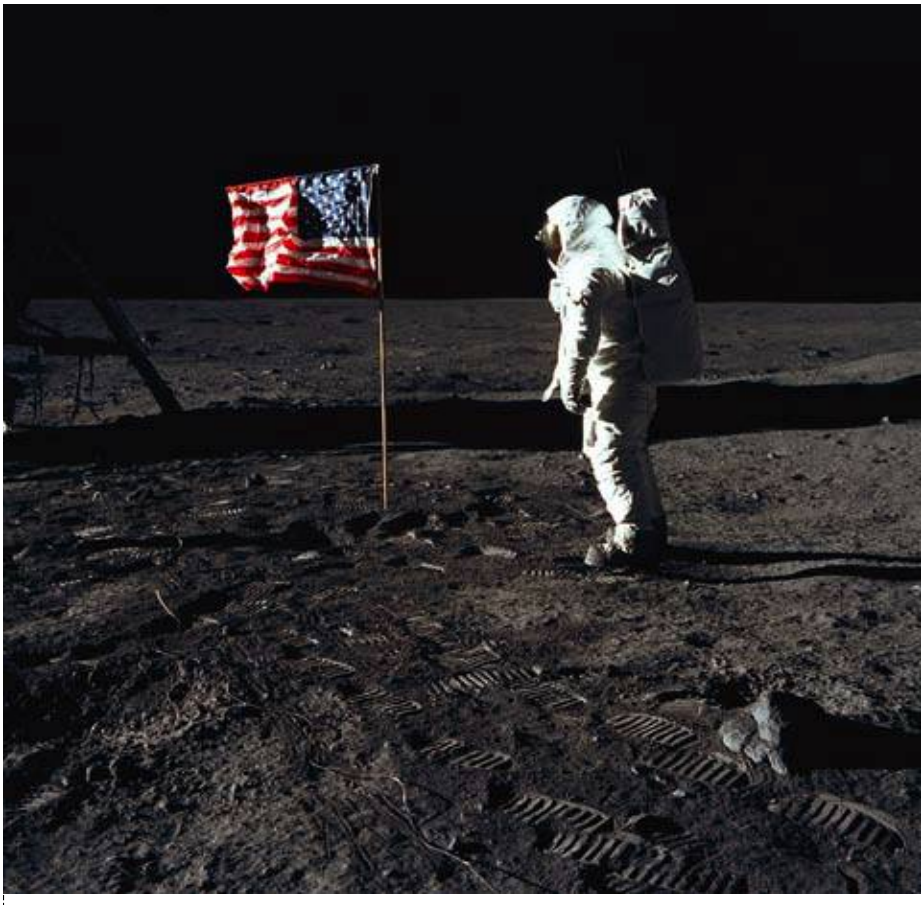
Q: Can you see the American flag Apollo 11 astronauts left on the Moon in 1969?

— **ROY STANFORD,** TEMPLE HILLS, MARYLAND

A: No, the flag is too small for Earth-based observers to see.

The 33-foot-wide (10 meters) Keck telescopes — currently the largest on Earth — can't resolve features as small as the 4-foot-long (1.25m) American flag Apollo 11 mission astronauts left on the Moon when they landed there July 20, 1969. To see the flag from Earth would require a telescope some 650 feet wide (200m).

The Hubble Space Telescope can see things 200 feet (60m) across or larger on the Moon, but the telescope isn't large enough or close enough to resolve anything smaller. Hubble's aperture is 7.9 feet (2.4m), and the telescope orbits 360 miles (575 km) above Earth's surface. But the 2,160-mile-wide (3,480 km) Moon lies an average distance of 239,000 miles (385,000 km) away from Earth. Even the space-based Hubble Space Telescope isn't powerful enough to get a good view of the flag. — **LAURA LAYTON,** ASSOCIATE EDITOR



APOLLO 11 ASTRONAUTS, including Buzz Aldrin, pictured here, planted the American flag on the Moon during their visit to Earth's nearest neighbor July 20, 1969. The Apollo 11 spacecraft touched down at the Sea of Tranquillity. NASA

FAR SIGHT

Q: Why can the Hubble Space Telescope see distant galaxies but not exoplanets?

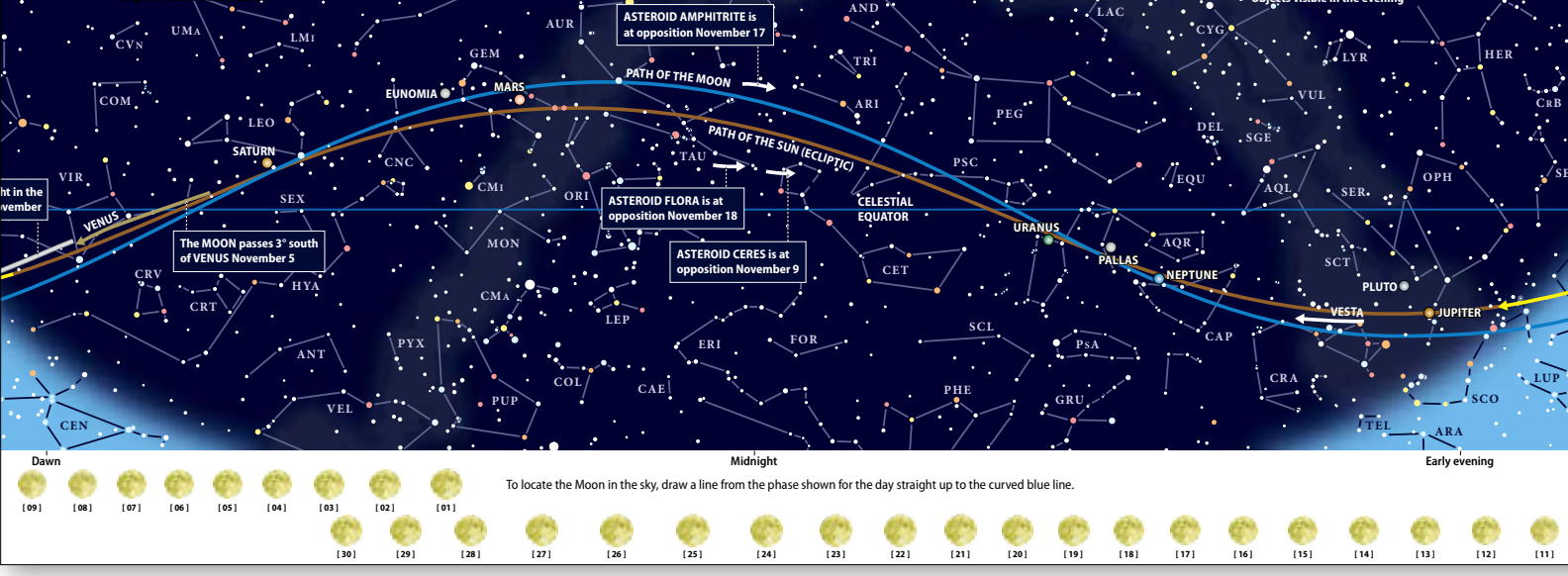
— **DAVID McKENNA,** SAN BRUNO, CALIFORNIA

A: Despite Hubble's marvelous ability to image distant galaxies, the telescope isn't able to image extrasolar planets. The problem isn't so much that nearby planets are faint — it's that exoplanets orbit stars that are about a billion times brighter than they are in visible light. **Light reflected from these extrasolar planets becomes lost in the glare of their host stars.**

In angular size, Hubble can resolve features as small as about 0.1". If not for this contrast problem, the instrument could image a planet orbiting at Earth's distance from the Sun around a nearby star. NASA plans to build a specialized space telescope, called the Terrestrial Planet Finder, within 10 years that will be able to separate a planet's light from starlight and yield the first images of extrasolar Earths. — **ALAN BOSS,** CARNEGIE INSTITUTION OF WASHINGTON

ROGUE ASTEROID

Q: Could an asteroid the size of the one that killed the dinosaurs knock Earth out of its orbit and create a global climate shift? — **LUKE BOULAIS,** PITTSFIELD, MASSACHUSETTS



THIS MAP UNFOLDS the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month. What an observer sees in the sky overhead depends on his or her location and the time of night. To see November's "Planets this month" chart at full size, go to page 44. *ASTRONOMY*: ROEN KELLY

A: The impact of an asteroid the size of the one that probably "did in" the dinosaurs would result in a major global climate change, but not by knocking Earth out of its orbit. A 6-mile-wide (10 km) asteroid would be a mere speck compared to the size of Earth and wouldn't affect the planet's orbit in any significant way. It would, however, probably cause extinction of some species, not to mention a lot of suffering.

There would probably be a major loss of human life from such an event, as well as a severe shock to cultures and civilization. — **MIKE REYNOLDS,** FLORIDA COMMUNITY COLLEGE, JACKSONVILLE, FLORIDA

IN THE KNOW

RESOLUTION
A telescope's or camera's ability to pick out fine detail.

EXOPLANET
A planet orbiting a star other than the Sun; also called an extrasolar planet.

ECLIPTIC
The plane of Earth's orbit around the Sun; as seen from Earth, the annual path the Sun follows through the background stars.

RIGHT ASCENSION
The angular distance of a celestial object east of the vernal equinox; the celestial-sphere equivalent of longitude.

STRETCH OR RIP?

Q: Do black holes stretch or rip the fabric of space-time?

— **RYAN FRAASE,** BUFFALO, NORTH DAKOTA

A: Einstein's "classical" theory of general relativity predicts that nearby space is "stretched." Cosmologists don't know whether space-time can be "ripped." General relativity governs the behavior of objects much larger than an atom — Earth, the Sun, and Sagittarius A*, the black hole astronomers believe lies at the center of our galaxy.

Stretching affects both space and time. For example, a clock near a black hole's event horizon appears to "run slow" to a distant observer. Of course, to a person at the black hole's "surface," our clock appears to run fast. He does not experience time running slowly because everything is slowed down, including his brain.

Intense tidal forces — changes in the gravitational force across an object — near a black hole would tear apart any nearby matter. The tidal forces tear only matter, not space. Cosmologists can only speculate whether or not space-time can be ripped or torn. — **SIMON DEDEO,** KAVLI INSTITUTE FOR COSMOLOGICAL PHYSICS, UNIVERSITY OF CHICAGO

MAP USE

Q: How does the "Planets this month" foldout map work? I don't see any time given for the map, unlike the circular star map on the following page. — **BERNARD MEYER,** NEWTOWN SQUARE, PENNSYLVANIA

A: When you look at a globe, you can see only a part of the whole — and what you see depends on your viewing angle. The circular star map shows only the portion of the sky visible during evening hours from middle-northern latitudes.

A wall map, on the other hand, shows you the entire world at a glance. **Our "Planets this month" map shows the entire zone near the ecliptic as if you were viewing the sky from the center of a transparent Earth.** It provides only a generalized overview of how the Sun, Moon, planets, and bright comets and asteroids move against the stars during the month (i.e., what is visible in the night sky for all observers).

An observer's location and observing time will limit what's actually seen from the "Planets this month" chart to the portion of sky above the horizon then.

The map's center lies at the right ascension of local midnight at midmonth. Objects visible in the morning sky are at left, those visible in the evening sky are at right. — **FRANCIS REDDY,** ASSOCIATE EDITOR

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Meet astronomers on the front lines of protecting Earth.

/// BY ROBERT REEVES

Who will save us from a killer asteroid?

In 1908, a brilliant fireball streaked

northwest across the sky over Siberia and exploded 3 to 6 miles (5 to 10 kilometers) above ground near the Tunguska River. Releasing 1,000 times more destructive energy than the atomic bomb dropped on Hiroshima in 1945, the blast scorched and flattened an area the size of metropolitan Washington. Scientists think the Tunguska object was either a stony meteor or a comet fragment measuring no more than 230 feet (70 meters) across.

Compared to infamous killer asteroids like the 6-mile-wide (10 km) impactor that hastened the dinosaurs' demise, the Tunguska object wasn't huge. But it wouldn't take a particularly massive comet or asteroid to devastate a populated area or to unleash destructive and deadly tsunamis after an ocean impact. If the Tunguska blast occurred over modern-day Washington — home to more than 550,000 people — the number of casualties would be horrific.

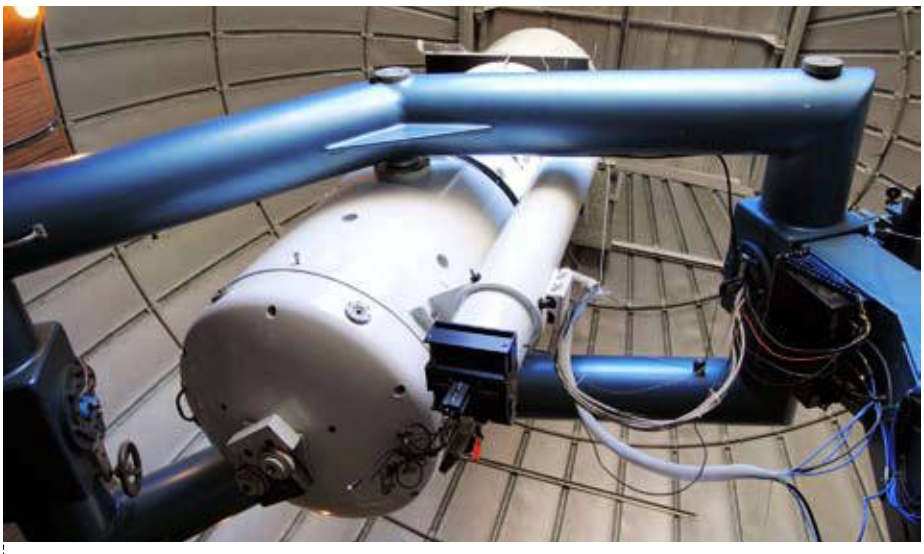
To truly safeguard Earth, we would need to locate and track thousands of potentially hazardous objects and be ready to divert them before they strike. NASA supports the work of five teams searching for comets and asteroids 3,280 feet (1 kilometer) in diameter or larger. The ones considered potentially hazardous are known as near-Earth objects, or NEOs. These are solar system bodies whose closest approach to the Sun is less than 1.3 astronomical units (AU). (One AU is about 93 million miles [150,000 km], the average distance from Earth to the Sun.) These orbits bring NEOs worryingly close to Earth, leaving open the possibility of an eventual collision.

The vast majority of NEOs are asteroids. The best estimate today is that the solar system contains up to 1,100 asteroids 1 km or larger. NASA aims to find 90 percent of them by the end of 2008.

The impact of a large asteroid or comet could alter human history — maybe end it — but even a smaller "city-buster," only a few dozen meters across, could inflict major economic and social disruption. That's why Congress passed a law in 2005 setting the ultimate goal of U.S. NEO surveys as locating 90 percent of NEOs 460 feet (140m) and larger by 2020. The solar system may harbor as many as 100,000 NEOs in this size range.

SPACE IMAGERY CENTER (UNIVERSITY OF ARIZONA)

ASTEROID-HUNTERS with the Catalina Sky Survey (CSS) pose at their home base, the University of Arizona's Lunar and Planetary Laboratory. Full-time staffers, from left to right, are Stephen Larson and Richard Hill (top row); Richard Kowalski and Alex Gibbs (middle row); Eric Christensen, who recently left the survey, and Edward Beshore (bottom row).



READY FOR ACTION in Arizona's Santa Catalina Mountains, this 28-inch (0.7 meters) Schmidt camera is the second-largest telescope of its kind in the United States. It is one of three instruments the Catalina Sky Survey uses to find hazardous asteroids. ROBERT REEVES

THE 1908 AIR BLAST over Siberia took few lives because, fortunately, it lashed a remote and sparsely populated landscape. Had the same event occurred just hours earlier, it could have leveled a Russian town or city, killing thousands of people. SMITHSONIAN INSTITUTION

Recently, I spent several nights visiting NEO hunters at the Catalina Sky Survey (CSS), based in Tucson, Arizona. The dedication and technology CSS observers deploy to detect space rocks 1 km or larger gave me an appreciation for the challenge future NEO-hunters face when they go after the 140m-sized objects.

The CSS is born

Stephen M. Larson of the University of Arizona's Lunar and Planetary Laboratory in Tucson currently directs the Catalina Sky Survey. CSS astronomers operate a 28-inch (0.7m) and a 60-inch (1.5m) telescope at two locations in the Santa Catalina Mountains north of Tucson. Both scopes are equipped with large-format CCD cameras.

CSS runs a third telescope, the 20-inch (0.5m) Uppsala Schmidt, at Siding Spring, Australia, in collaboration with the Australian National University (ANU). This makes CSS the only NEO survey that observes in both the Northern and Southern hemispheres. Among the Australian members of the CSS is ANU astronomer Robert McNaught. He discovered Comet McNaught (C/2006 P1) — which blazed in the Southern Hemisphere in January and February 2007 — on a CSS survey image taken with the 20-inch Schmidt telescope.

The CSS started in 1998. NASA provided grants of $500,000 for Larson to refurbish the telescopes. The money has paid generous dividends: 1,024 NEOs were charted as of June 2007. In terms of total NEOs discovered, Larson's team has led the other four surveys since 2005.

Teamwork

The CSS team consists of Larson, five full-time staff observers, and two part-timers. Typically, each observer operates a telescope for alternating 3-night observing runs. Observing ceases for several days before and after Full Moon, whose glare makes it much harder to detect faint asteroids and comets. Taking into account cloudy weather and the Moon, the survey operates on about half of all nights.

The CSS has an edge on the other NASA surveys: Siding Spring. Four of the five NASA surveys operate in the Southwest, with a fifth in California. This means a large weather system can blind most U.S. NEO hunters. At Siding Spring, McNaught and his colleagues Gordon Garradd and Donna Burton help fill the gaps.

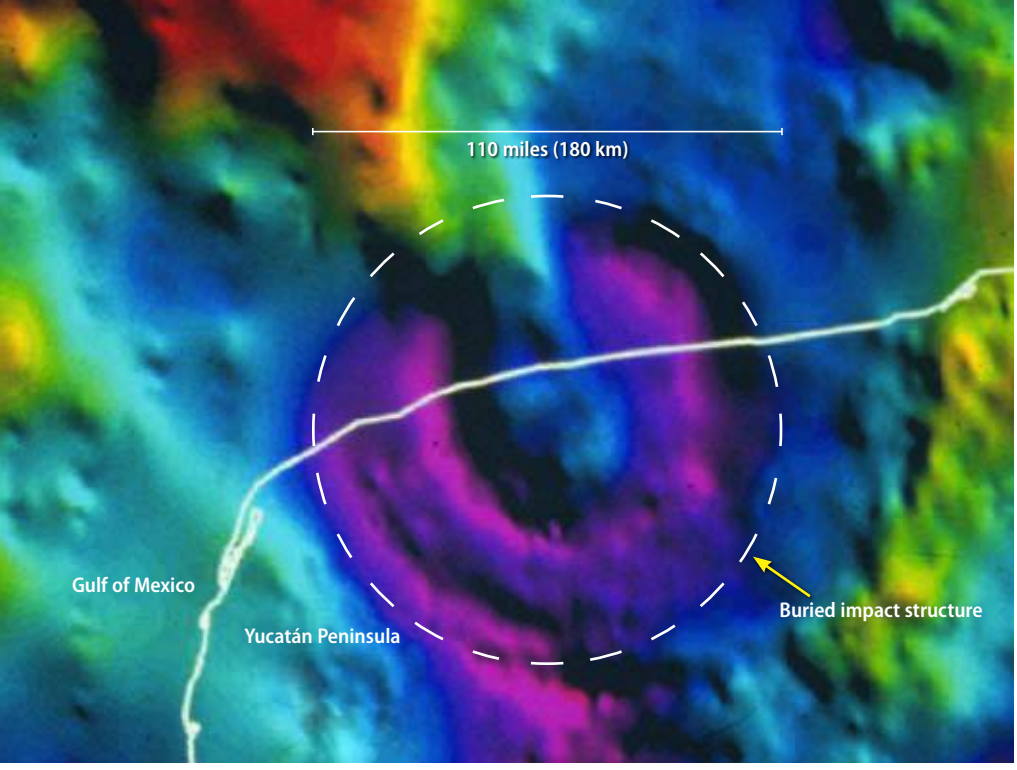
During Full Moon, the Tucson team troubleshoots problems and upgrades equipment, looking for ways to improve survey efficiency. Just a small improvement here and there adds up to significant gains in the number of images processed and new NEOs discovered.

The team's urgency isn't misplaced. They hunt for NEOs every clear night with the knowledge they could be finding an asteroid or comet that, ultimately, may be heading our way. "I get personal satisfaction knowing that we are mapping asteroids that may be visited in the future by spacecraft," says CSS staff observer Richard "Rik" Hill. "There is also great fulfillment in being part of man's first attempt to try and prevent the possibility of impacts disrupting life on Earth."

How to spot NEOs

A night of NEO-hunting starts with partitioning the sky into survey areas. Each partitioned area, displayed on a computer monitor, equals the telescope's observing field. Software commands the telescope to visit all of the selected fields four times in the order they were selected. Each exposure

Robert Reeves *is a writer in San Antonio. He is the author of* Introduction to Digital Astrophotography *(Willmann–Bell, 2005).*



OVERLAPPING THE NORTH COAST of Mexico's Yucatán Peninsula, this vast impact scar lies buried beneath seafloor sediment. It marks the spot where a 6-mile-wide (10 kilometers) asteroid bull's-eyed Earth about 65 million years ago. V. L. SHARPTON (UNIVERSITY OF ALASKA, FAIRBANKS)

METEOR CRATER, ARIZONA, testifies to the destructive potential of asteroids and other space debris. An iron-rich meteorite only 30 to 160 feet (10 to 50m) across excavated this 4,000-foot-wide (1,200m) hole about 50,000 years ago. DAVID RODDY AND KARL ZELLER (USGS)

lasts 30 seconds. Computers read out the data from the CCD detectors as the telescope slews to the next search field. It is truly pushbutton astrophotography. On a productive night, the observers can image 1,800 square degrees of sky four times.

To find an NEO, computers compare the four different shots of each coverage area to identify objects that change position over time. These could be moving objects — asteroids or comets. Former team member John Brownlee wrote the software that recognizes moving targets between the four successive search images. The software is called CON4, for "connect the four dots."

To confirm the observation, the astronomers use display software to flip between, or "blink," the four images. This highlights an asteroid or comet's motion across the background stars. If the target moves in a straight line with consistent motion between exposures, then it's a good candidate to be an NEO. Asteroids look like sharp points; comets are fuzzy dots.

Next, the CSS observers compare their "hits" with known asteroids stored in a database at the Minor Planet Center in Cambridge, Massachusetts. A quick check can exclude many suspects as previously discovered asteroids and comets. But if the object is not in the database and shows motion consistent with an NEO, it brings an exciting moment that can help keep the observers awake late at night.

"The constant discovery is exciting," CSS team member Alex Gibbs explains. "There aren't many areas of research where you can discover things that no one has seen before."

Unfortunately, during my visit the CSS observers found no potentially Earth-threatening asteroid. But, on the last night, they did spot the telltale fuzzy dot of a comet. However, it turned out to be an old friend, Comet Encke, which I had not seen since photographing it with my own Schmidt camera in 1982.

Meeting the future threat

Of all the NEOs known, none appears to have its crosshairs on Earth. Indeed, Larson says, "My biggest surprise is the next impactor has not been identified yet."

As of January 2007, there were 832 known potentially hazardous asteroids (PHAs), defined as those 140m and larger, and having orbits 0.05 AU or less from Earth's own path around the Sun. At this distance — about 4.6 million miles (2.9 million km) — the tug of Earth and the Moon on a passing NEO could gradually drag it into a collision course. It is only a matter of time before an NEO with a dangerous orbit shows up. Will we be ready?

Right now, we are not, according to "planetary defense" proponents like the California-based B612 Foundation. The foundation — composed primarily of scientists, engineers, and other technical experts — advocates for a survey of all potentially hazardous NEOs and development of a defense system to prevent collisions with Earth. The B612 Foundation's solution: a spacecraft to rendezvous with an asteroid while it's still far from Earth and nudge it into a safer orbit.

Before we can start building any kind of NEO-herding device, we need advance warning of hazardous asteroids heading our way. Larson endorses the Congressional mandate to survey for asteroids 140m and larger. "We think it is a good idea, since the smaller objects can still cause local and regional damage," he says.

Because PHA orbits are subject to change, they demand constant monitoring to provide sufficient advance warning to respond to the threat. "The only way we can identify them is to observe all near-Earth objects long enough to know if they are PHAs, just like we observe all objects with NEO-like motion to determine if they are NEOs," Larson explains.

The bottom line: To successfully defend the planet from NEOs, we will need to identify up to 100,000 unique comets and asteroids, and then monitor PHAs that could evolve Earth-impacting orbits. But the current system for detecting NEOs is not up to the more demanding task.

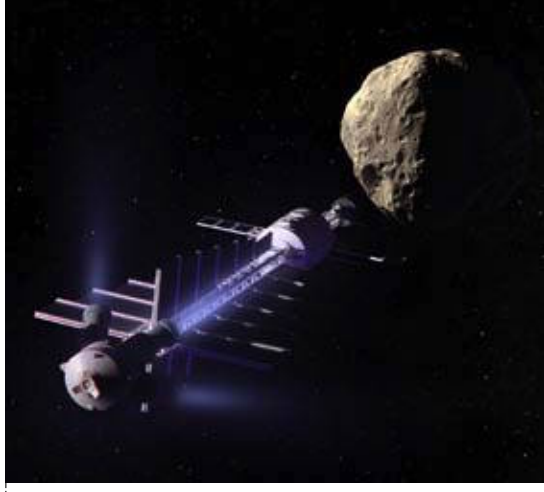
"This clearly requires a new level of technology that will allow covering more sky in shorter time and to much fainter magnitudes," Larson notes. That means bigger telescopes, more telescopes, more-sensitive detectors, and faster computing.

Souped-up survey scopes

Fear not, earthlings, help is on the way: Two advanced new survey telescopes are coming. Equipped with ultrasensitive CCD cameras and ultrafast data-processing power, they are likely to significantly contribute to planetary defenders' long-term goal of identifying all potentially hazardous objects in the solar system.

One of the instruments on deck is the Panoramic Survey Telescope and Rapid Response System, or Pan-STARRS. Designed by the University of Hawaii's Institute for Astronomy, Pan-STARRS will consist of four 5.9-foot (1.8m) telescopes ganged together into an instrument reminiscent of a *Star Wars* laser cannon.

Each telescope will sport a 1,400-megapixel CCD camera — the largest digital cameras ever built. Together, the telescopes will survey the entire sky visible from Hawaii several times each month. The telescope's designers promise Pan-STARRS will complete the survey for NEOs 1 km and larger and detect others as small as 980 feet (300m) across.



TO DIVERT AN ASTEROID, the mass of a "gravity tractor" would tug the potential impactor into a safer orbit. DAN DURDA

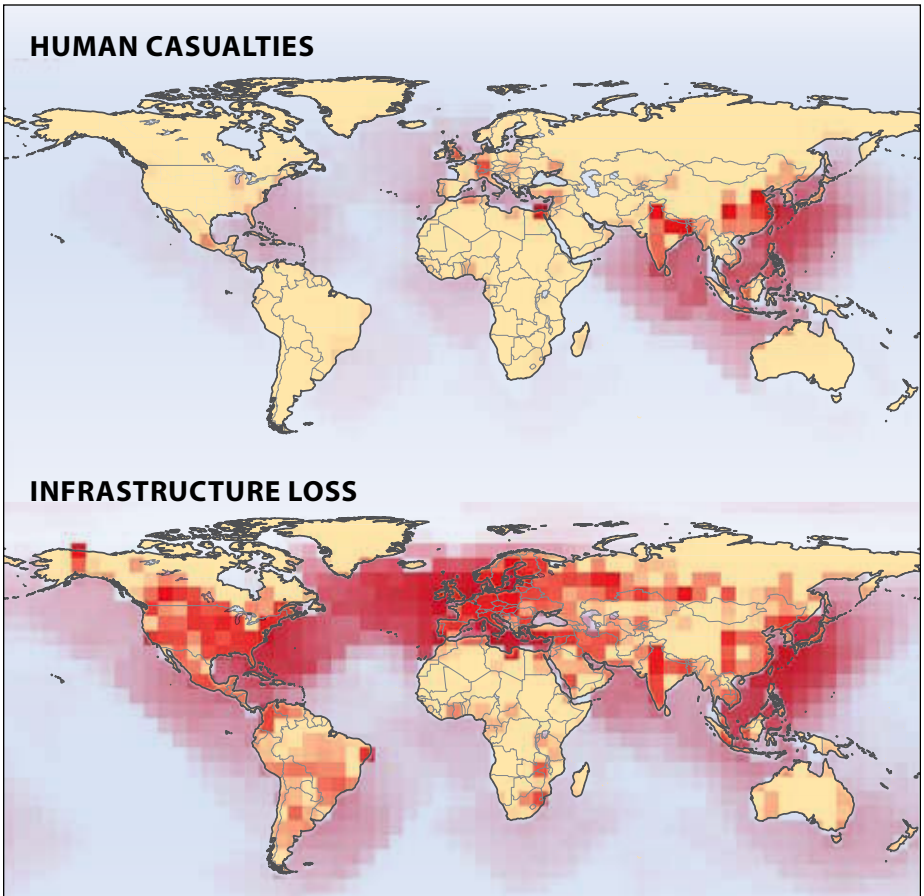
Another mega-survey scope in the works is the Large Synoptic Survey Telescope, or LSST. After it begins operation in 2013 on a mountain in Chile, the 27.5-foot (8.4m) LSST will image a swatch of sky about 40 times the area of the Full Moon every 15 seconds. Its CCD camera will pour out enough bits and bytes of data every night to fill 7,000 DVDs. Twenty-one organizations, including search-engine giant Google, have teamed up to build LSST.

Save Earth: help wanted

The new digital survey telescopes will speed up the NEO detection rate. But, for the time being, old-fashioned determination still rules, and professionals like Larson don't claim all the credit.

After a new object is spotted, the Minor Planet Center requires follow-up observations to calculate the object's orbit and confirm it's an NEO. Because there are only so many professional observers available to perform the vital follow-up, amateur astronomers make valuable contributions to the NEO surveys. Without the efforts of amateurs worldwide, the various surveys could not meet their goals.

As a longtime observer, I've seen and photographed NEOs against the background stars. It's a thrill to watch a solar system body glide through outer space. And by contributing to the surveys, we amateurs can become defenders of Earth. A



AN ASTEROID STRIKE WOULD HAVE GLOBAL EFFECTS, but what type and for whom? University of Southampton (UK) researcher Nick Bailey created software, ***NEOimpactor,*** to predict the casualties and destruction small asteroids would inflict at different locations on land and in the oceans. The greatest human casualties (top map, indicated in red) would occur due to tsunamis inundating the coastlines of the Indian and Pacific oceans. Damage to infrastructure (bottom) would concentrate in built-up areas on the Atlantic Ocean, home to many large coastal cities and off-shore oil-drilling rigs. NICK BAILEY (UNIVERSITY OF SOUTHAMPTON)

ONLINE EXTRA To learn the latest science on the 1908 Tunguska explosion, go to www.astronomy.com/toc.

Parks Optical's 6- and 8-inch Newtonian reflectors deliver top-notch optics at a reasonable price. /// **BY PHIL HARRINGTON**

Astrolight reflectors offer quality optics

The Astrolight AZ6 and AZ8 Newtonian reflectors from Parks Optical combine quality optics with a simple mount at a price that won't break the bank. What more could a cost-conscious amateur astronomer ask for in a scope?

The 6-inch f/6 AZ6 and 8-inch f/6 AZ8 both feature the company's trademark glossy white tube assembly and American-made Pyrex mirrors. But instead of massive equatorial mounts, each rides on a basic alt-azimuth mount on top of a pier. Like a Dobsonian mount, the Astrolight mount moves left and right in azimuth, and up and down in altitude. This makes the scope simple for novice stargazers to use almost right out of the box.

Both Astrolight scopes address the complaint that most small Dobsonian-mounted reflectors are too low to the ground. When aimed vertically, the AZ6's eyepiece stands 58 inches (1.5 meters) high, while the AZ8's is 67 inches (1.7m). When aimed horizontally, the eyepieces are 43 inches (1m) off the ground. I like to observe standing up, so I appreciate this convenience.

The telescopes' optics are housed in glossy white fiberglass tubes rather than the more common steel. They look great, but fiberglass has its pluses and minuses. While lightweight and strong, fiberglass tends to retain more heat than metal and reradiates that heat slowly at night. A telescope's optics must acclimate to the outdoor ambient temperature to provide a sharp focus. This adds many minutes of waiting after setup, depending on the temperature where the scope was stored.

Both the AZ6 and AZ8 scopes use the same Astrolight mounting. To compensate for the different tube diameters, the mount's tapered arms can be unbolted, swapped left to right, and reattached. When the mount's arms are farthest apart, it is set up for the 8-inch tube. When they are closest together, they accommodate the 6-inch tube. I thought that was quite clever. Each tube comes with a pair of mounting rings that can be loosened to balance the scope in its cradle.

To keep weight down, the Astrolight mount uses a unique mix of metal and composite material. The 4-inch-diameter (10 centimeters) pier is steel, while the alt-azimuth mount is glass-reinforced, high-impact polymer. The pier's three legs are also made of the same composite material. When assembled, the mount and pier weigh just 25 pounds (11 kilograms).

The Astrolight pier and mount assemble easily. Each of the three legs attaches to the steel pier with a single thumbscrew. A ring-shaped collar then slips over the pier and legs to lock them in place. The alt-azimuth mount comes preassembled, but the user must attach it to the top of the pier. The azimuth axis rides on two small ball-bearing assemblies sandwiching the mount's head. Turning a hex-keyed flat-head bolt that passes through the mount and threads into the pier's cap adjusts the azimuth tension. It took some finesse to

► PARKS OPTICAL'S AZ6 6-inch f/6 Astrolight Newtonian reflector rides on an alt-azimuth mount atop a steel pier. This puts the scope at eye level for most observers. High-quality optics and ease-of-use are the hallmarks of this scope.

EQUIPMENT IMAGES: *ASTRONOMY*: WILLIAM ZUBACK; BACKGROUND: TONY HALLAS

▲ THE AZ8 8-inch f/6 Astrolight's optical tube has 2 inches more aperture than the AZ6 and a similar Pyrex mirror.

PARKS

A THREE-LEGGED, 4"-diameter (10cm) steel pier supports an alt-azimuth mount. The 45"-tall (114cm) mount-and-pier system weighs 25 pounds (11kg), and it has a 21" (53cm) circular footprint.

A CRAYFORD-STYLE focuser provides smooth focusing. This 1¼" rack-and-pinion focuser has plenty of travel and brought each eyepiece tested to its focus point. A thumbscrew holds eyepieces in place.

get that tension right. Tightening two large side-mounted knobs adjusts altitude friction on the mount.

Testing the optics

The test telescopes arrived directly from the Parks factory in California. Unfortunately, the shipment was a little rough. Somewhere along the way, the AZ6's primary mirror broke free of the silicone adhesive holding it to its cell and banged around inside the telescope tube. By the time it arrived on my New York doorstep, the instrument was effectively destroyed. I inspected and repacked it and returned it to Parks for replacement. Thankfully, the AZ8 and second AZ6 arrived unscathed.

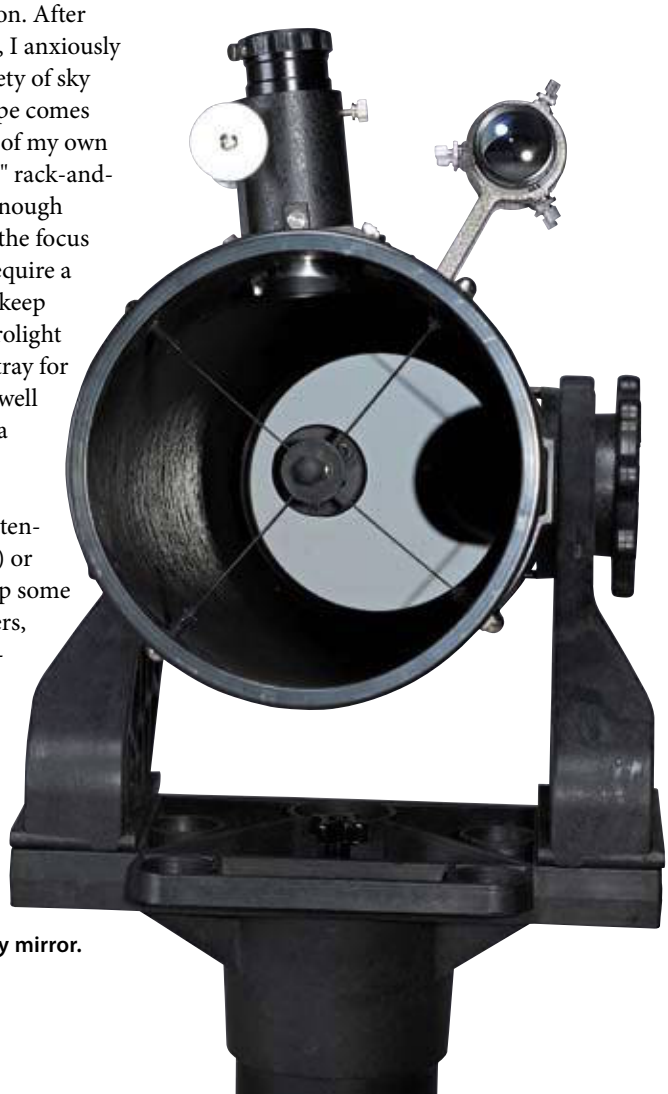
Both the AZ8 and replacement AZ6 arrived with their primary mirrors out of collimation. I believe this was because each mirror cell's three lockdown screws (which the included instructions say should be tightened after the primary's tilt is set) were left loose. Although the illustrated instructions detail the collimation process, neither instrument comes with an alignment tool or a center-spotted primary mirror to simplify that process. At f/6, precise collimation is required to get the most out of the AZ6 and AZ8. So, at a minimum, owners will need a sight tube when adjusting either Astrolight.

I was eager to find out if these telescopes lived up to Parks' good reputation. After setting them up this past winter, I anxiously aimed each scope toward a variety of sky objects. Because neither telescope comes with an eyepiece, I used several of my own for these tests. The standard 1¼" rack-and-pinion focuser had more than enough travel to bring each eyepiece to the focus point, including a couple that require a large amount of back-focus. To keep everything at the ready, the Astrolight mount has a built-in accessory tray for holding up to four eyepieces as well as a few filters and maybe even a small flashlight.

Parks' optics are impeccable. Whether it was the filamentary tendrils of the Orion Nebula (M42) or the twinkling gems that make up some of winter's gleaming open clusters, the AZ6 and AZ8 did not disappoint. I kept returning to the Orion Nebula, bouncing between the wide view through a 22mm eyepiece and zeroing in on the Trapezium with a 5mm. On one night of unusually steady seeing, both scopes easily revealed the Trapezium's elusive E and F stars.

Saturn, rising in the east then, also put on a wonderful show. The Cassini Division was clear in both scopes every time I turned its way. Each also revealed wonderfully fine details in Jupiter's belted atmosphere during some frigid early morning sessions.

Star-testing proved that those images were no accident. With a 5mm eyepiece in place, I aimed each telescope toward a 3rd-magnitude star and slowly racked the image in and out. I saw virtually identical images on either side of focus, proving the optics are indeed top-notch. Both instruments



OPTICAL PERFORMANCE makes the Astrolight Newtonian reflectors a good choice. This view down the AZ6's optical tube reveals its annealed, diffraction-limited Pyrex primary mirror.

CONTACT

Parks Optical, Inc.
750 E. Easy Street
Simi Valley, CA 93065
[t] 805.522.6722
[w] www.parksoptical.com

Phil Harrington *is an* Astronomy *columnist and contributor. Find his column,* Phil Harrington's Binocular Universe, *on page 14.*

TWO INCHES of aperture separate the Astrolight AZ6 6-inch Newtonian reflector from the AZ8. Each scope has the same high-quality optics, and both come with a Crayford-style focuser and spotting scope. A lightweight fiberglass optical tube houses each scope's optics.

produced smooth, symmetrical patterns with virtually no indication of spherical aberration and only a slight amount of astigmatism. I judged the 8-inch mirror to be slightly better than the 6-inch, but only by a small margin.

Likes and dislikes

I liked the Astrolights' optical performance, but I was a little disappointed by the mount for several reasons. Despite my attempts to adjust the tension on the altitude and azimuth axes, the mount's motions were not as smooth as many Dobsonian-style mounts I have used in the past. To check the Astrolight mount's sturdiness, I rapped the telescope tube lightly with my palm while looking through the eyepiece. Then I counted how many seconds it took for the image to settle down. Even with both axes locked, images through the AZ8 took a long 6 seconds to calm down. The lighter, shorter AZ6 took 5 seconds. And maybe it's because of my own big feet, but I also found the pier's three black legs easy to trip over in the dark. Each leg extends 21 inches (0.5m) from the pier. I would recommend owners mark the tip of each leg with white duct tape. This will make them easier to see and less of a trip hazard, especially when viewing in groups or with younger observers.

I was impressed with the optical performance of the AZ6 and the AZ8 Astrolight reflectors overall. Once collimated, images were clear and crisp, offering delightfully detailed views of the planets and deep-sky objects. Although the mount's performance proved somewhat lacking, I appreciated having the eyepiece at eye level. This is a plus during longer observing sessions.

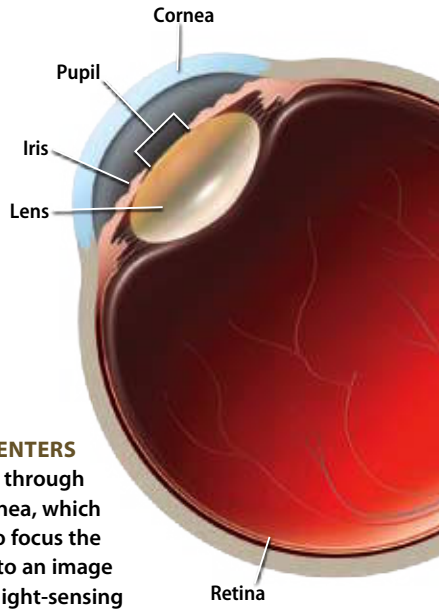
Parks Optical's 6-inch and 8-inch Astrolight Newtonian reflectors deliver a lot of bang for the buck in terms of aperture, ease-of-use, and optical performance. These eye-level-mounted scopes make a good first telescope for the amateur on a budget. With simplicity and quality optics front and center, these new reflectors will help newcomers to the hobby of astronomy answer the question, "Which Newtonian reflector fits my needs?"

/// SPECIFICATIONS

	ASTROLIGHT AZ6	ASTROLIGHT AZ8
Mirror diameter:	6 inches (152 millimeters)	8 inches (203mm)
Focal length:	910mm	1,220mm
Focal ratio:	f/6	f/6
Magnification (with 25mm eyepiece):	36x	49x
Field of view (with 25mm eyepiece):	1.3°	1°
Secondary mirror:	1.55 inches (39mm)	1.83 inches (46mm)
Tube length:	36" (91 centimeters)	48" (122cm)
Tube outer diameter:	7.3" (19cm)	9.3" (23.6cm)
Tube weight:	12 pounds (5.4 kilograms)	21 pounds (9.5kg)
Mount height:	45" (114cm)	45" (114cm)
Eyepiece height (vert.):	58" (147cm)	68" (173cm)
Mount weight:	25 pounds (11kg)	25 pounds (11kg)
Footprint:	21" (53cm) circle	21" (53cm) circle
Altitude travel:	Horizon to zenith	Horizon to zenith
Azimuth travel:	360°	360°
Price:	$799	$999

Like any surgery, laser vision correction has its pros and cons — especially for observers. /// **BY DANIEL PENDICK**

Is LASIK for you?



LIGHT ENTERS the eye through the cornea, which helps to focus the light into an image on the light-sensing retina in the back of the eyeball. The cornea is rigid, so the flexible inner lens of the eye changes shape slightly to bring the image to a fine focus on the retina. *ASTRONOMY*: ROEN KELLY

Your eyes are your onboard optical

system, like a pair of fine, irreplaceable telescopes. When deciding whether to undergo LASIK or some other kind of vision correction procedure, amateur astronomers have a particular concern: Could something go wrong and reduce their enjoyment of the hobby? The short and honest answer is yes.

"A good result isn't certain," says Myron Wasiuta, an amateur astronomer and an optometrist at the Access Eye Center in Fredericksburg, Virginia. "No surgeon can guarantee what is going to happen."

The risk of serious, permanent complications from laser correction is relatively small with an experienced surgeon using the best technology available. And you should always undergo a thorough preoperative medical evaluation to establish that you are a good candidate for surgery.

Decisions about any medical procedure are highly individual. Active stargazers with excellent vision at the eyepiece might be reluctant to risk harming their eyesight for the convenience of not having to wear glasses. On the other hand, observers with certain types of visual deficits can end up with a greatly improved experience at the telescope after laser correction.

Wasiuta did. As an adult, he developed distortions in his vision that turned Venus into a spiky blob. Naked eye, he could see 6 stars in the Pleiades — about average — but only under ideal conditions. Within 6 weeks of laser correction, Wasiuta could resolve 9 stars in the cluster.

The bottom line is that observers who have their vision corrected are not any more at risk of complications than anyone else, but they may have more to lose from a bad outcome. Here's what you need to know to make an informed decision with your eye-care provider about laser surgery.

Laser basics

LASIK is one of five procedures approved by the U.S. Food and Drug Administration for correcting refractive errors in vision (see "The ABCs of laser vision correction on page 75). The three types of errors are:

- **Myopia:** You can see nearby objects clearly, but not faraway ones.
- **Hyperopia:** You can see faraway objects clearly, but not close-by ones.
- **Astigmatism:** Your vision at all distances is blurred by uneven focusing.

LASIK and the other refractive corrections allow most people to stop wearing eyeglasses or contacts for myopia, hyperopia, and astigmatism.

DIOPTRX corrector lenses attach to Tele Vue eyepieces. The lenses correct for up to 3.5 diopters of astigmatism. This may eliminate the need for eyeglasses or contacts in people with astigmatism only, but not if they also have myopia or hyperopia. DioptRX can be an alternative to laser eye surgery. *ASTRONOMY*: WILLIAM ZUBACK

All five procedures reshape the cornea to bring images to a sharper focus on the retina. The cornea accounts for about two-thirds of the eyes' refractive power, while the internal lenses provide fine focusing.

One of the five refractive surgeries, conductive keratoplasty (CK), corrects presbyopia — age-related difficulty reading — as well as hyperopia. The other four procedures do not help with presbyopia, so people who already use glasses for reading will have to continue doing so after surgery.

What could go wrong?

Data on surgical outcomes suggest that 6 months after refractive surgery, about 3 percent of people have some sort of unresolved problem, and 0.5 percent have a serious unresolved problem. The most common side effect is dry eye. This causes an itchy, teary sensation, as if you have grit in your eye. This happened to Magda Streicher, a stargazer in Polokwane, South Africa, who underwent laser correction. Streicher attributes her dry eye to a cornea scratched during surgery. The irritation sometimes cuts observing sessions short.

All refractive procedures introduce changes in vision called higher-order aberrations, notes Ivan Schwab, an eye surgeon and professor of ophthalmology at the University of California, Davis. Aberrations distort images as they pass through the cornea. Common surgery-induced aberrations

include coma, astigmatism, halos, glare, and starbursts. Some aberrations' effects are worse at night. Before you swear off vision correction for life, keep in mind that higher-order aberrations from surgery are not always even noticeable, Schwab explains. "Some may be bothered, but most won't."

But he also acknowledges astronomical observers, who push the limits of their eyes' performance, might notice even subtle vision changes. Stargazers should consider this in their decision. "If your vision is okay with a small correction and you're happy doing your backyard astronomy," Schwab says, "beware that it's possible the procedure could introduce aberrations you didn't have before."

Observing through a wide-field eyepiece at low power may highlight the effect of aberrations. It can occur when the cone of light leaving the eyepiece overlaps the edge of the area reshaped by the laser, which is typically about 9mm across. At low power, the light cone is relatively wide, making it more likely to cross the edge and cause glare or some other effect. Even observers who have had great results with their surgery say they sometimes need to look straight into the eyepiece (that is, on axis) to avoid edge-glare effects.

Having to view on-axis is not necessarily a major burden, says Paul Maxson, an amateur astronomer in Surprise, Arizona. He had LASIK for his extreme farsightedness. Maxson says he is happy with the results of his surgery and would have it again. He went from a 20/350 prescription for "Coke bottle glasses" to 20/30. Stars now look "crisp and sharp" to him for the first time in years.

Another potential issue for observers is the decrease in contrast sensitivity associated with refractive surgery. Contrast sensitivity is the ability to discern between an object and its background or to detect subtle variations in tone. "There is always some loss," however small, Schwab says. This may be a concern for deep-sky observers, who measure success by their ability to see "faint fuzzies" such as galaxies, nebulae, and star clusters at the edge of visual detection.

Best time for laser surgery?

Major complications have become less common since the early days of laser vision correction in the 1980s, Wasiuta says. The science and technology of laser surgery has progressed. "Nowadays is really the best time ever to have this type of procedure," he says. "We know a lot more about who should have it and who shouldn't have it, and the technology has caught up to the point where we are now programming custom information from that person's individual eye and mapping it onto their cornea with micron accuracy."

Wasiuta is referring to "wavefront" or "custom" laser correction. It's based on the same technology astronomers use to identify and correct flaws in telescope mirrors. The surgeon uses a special machine to create a three-dimensional map of how light is altered as it passes into your eye and strikes the retina. The wavefront map then guides the laser reshaping of the cornea. Wavefront technology is intended to reduce aberrations, although Schwab adds, "I think it's been overhyped."

> Observers who have their vision corrected are not any more at risk of complications than anyone else, but they may have more to lose from a bad outcome.

But don't take his word for it; talk to your eye doctor. The decision to have laser correction depends on your needs and expectations, your tolerance for risk, your overall health and age, and even factors as mundane as the size of your pupils and the thickness of your corneas. You may decide that the best way to make sure you always have the stars in your eyes is simply to keep your eyeglasses on your face.

Daniel Pendick *is an associate editor of* Astronomy.

ONLINE EXTRA For tips on choosing an eye surgeon, see www.astronomy.com/toc.

THE ABCs OF LASER VISION CORRECTION

The following are all surgical procedures for correcting myopia (nearsightedness), hyperopia (farsightedness), and/or astigmatism (uneven cornea). Each procedure has pros and cons you should discuss with your eye doctor. — *D. P.*

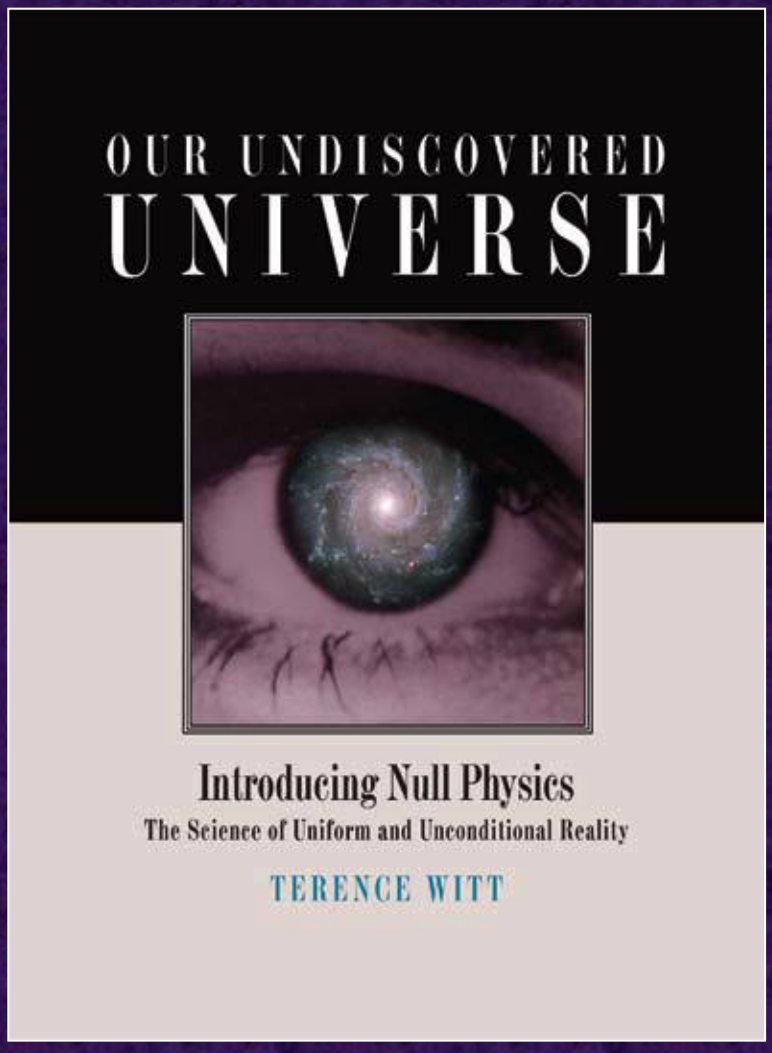
Conductive keratoplasty (CK)
CK was originally approved for hyperopia, but its main use today is correcting presbyopia (age-related difficulty reading). The surgeon uses a special tool to apply heat (from radio waves) to the connective tissue around the cornea. The heating steepens the angle of the cornea, improving vision for nearby objects. The effect wears off over time, however.

Epi-LASIK
Epi-LASIK is a variation on LASEK (see below). The surgeon uses a blunt plastic scraper to separate the cornea's outermost layer, the epithelium. After folding the flap of epithelial cells back, the surgeon reshapes the cornea with a laser before putting the epithelium back.

Laser in-situ keratomileusis (LASIK)
The surgeon creates a thin flap in the cornea, peels it back, and reshapes the cornea. The flap is put back in place after the procedure. LASIK is the most common surgical procedure performed in the United States. In a variation of the procedure called all-laser LASIK or bladeless LASIK, the surgeon uses a laser beam, rather than a metal cutting blade, to create the corneal flap.

Laser-assisted sub-epithelial keratomileusis (LASEK)
The surgeon dabs a chemical onto the surface of the cornea to separate the outermost cell layer or epithelium. The epithelial tissue is folded back. The surgeon reshapes the cornea with a laser and puts the epithelial cell back in place.

Photorefractive keratectomy (PRK)
The PRK procedure can correct myopia, hyperopia, and astigmatism. It is the main alternative refractive surgery to LASIK (see above). In PRK, the surgeon uses a laser to directly reshape the cornea surface after removing the topmost layer of cells, or epithelium. After surgery, the epithelium grows back.



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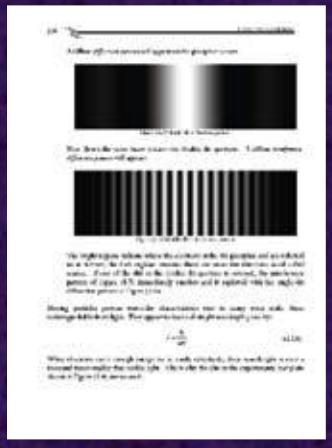

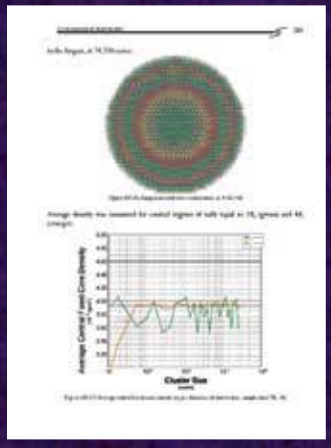

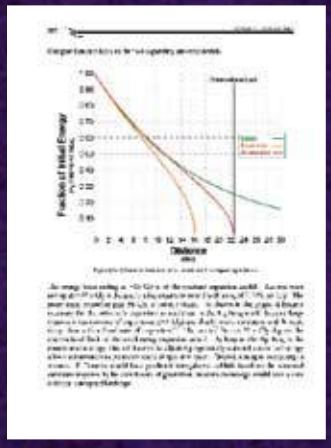

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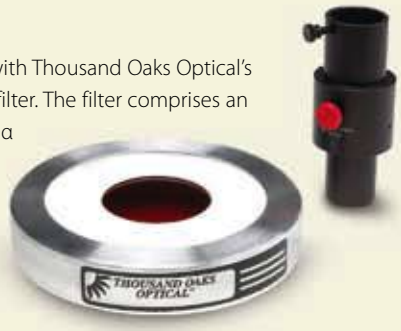

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The Deep South Regional StarGaze

(DSRSG) celebrates its 25th anniversary at Camp Ruth Lee in Clinton, Louisiana. DSRSG is the oldest continuous star party in the United States, and it welcomes more than 150 attendees from about 15 astronomical societies each year.

A 2006 DSRSG participant sets up his 10-inch telescope. In honor of DSRSG's 25th anniversary in 2007, planners added an extra day of observing. BARRY SIMON

DSRSG's site allows observers to spot 7th-magnitude objects with their naked eyes. A 3-acre field provides space for telescope setup, observing, and RV and tent camping. On-site cabins with equipment storage are available to rent. If you prefer more motel-like accommodations, attendees may stay at a nearby retreat center.

Activities will include observing, programs and speakers, movies, photography and telescope-building contests, a door-prize drawing, and special 25th anniversary events.

✉ Barry Simon at simon615@aol.com; 💻 www.stargazing.net/dsrsg.

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European Space Weather Week
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Ridgecrest, California. ☎ 760.375.5681; 💻 www.chinalakeastrosoc.org.

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Morgan County Observatory Foundation Star Party

Berkeley Springs, West Virginia. ☎ Kevin Boles at 304.258.1013; 💻 www.nitesky.org.

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Phoenix Astronomical Society Deep-Sky Star Party

Two Trees Observing Site, near Sedona, Arizona. ☎ 602.781.2414; 💻 www.pasaz.org.

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NOVEMBER 16

Central Montana Astronomy Society Star Party

Lewis and Clark National Historic Trail Interpretive Center, Great Falls, Montana. 💻 www.fs.fed.us/rl/lewisclark/lcic.

NOVEMBER 16–17

Greenleaf State Park Star Party

Braggs, Oklahoma. ✉ Glen Kilgour at observingcoordinator@okcastroclub.com; 💻 www.okcastroclub.com.

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INDEX of ADVERTISERS

20-20 Telescopes 82
Adirondack Video Astronomy 82
Adorama 11, 19
Agena Astro Products 85
Anacortes Telescope & Wild Bird 83
AP Theory 61
Aridian Publishing 76
Ash Manufacturing 85
Astro Gizmos 83
Astro-Physics 83
AstroMart.com 85
Astronomical Society of the Pacific 61
Astronomics 23
Astronomy.com 81
Astronomy Delight 83
Astronomy magazine 80
Astronomy magazine Calendar 60
Astronomy magazine Sweepstakes 64-65
Astronomy Technologies 18
Astrozap 61
Aurora Astro Products, LLC 82
Basic Books 53
Beam of Light Technologies 83
Beta Electronics 82
Big Bang Astronomy Shop 82
Binoculars.com 83
Bob's Knobs 85
Canon USA, Inc 79
Celestron 90
Davis Instruments 53
Denkmeier Optical 85
Durango Skies 85
Edmund Scientific 52
Efstonscience, Inc 61, 84
Farpoint Astronomical Research 84
Flo USA, Inc 85
Focus Camera 61, 82
Glatter Howard 85
Innovations In Travel 85
James Cook University 61
Jewelry Designs For Men 82
Jim's Mobile, Inc 19
Khan Scope Centre 83
Let's Talk Stars 61
Luckyduck.com 84
Lumicon 27
Meade Instruments Corporation 2, 3, 7
Mithec-Delamere Publishers 84
Moonlite Telescope Accessories 84
New Mexico Astronomical 61
Newport Glass Works 82
Obsession Telescopes 83
Oceanside Photo & Telescope 18
Orb Publishing 83
Orion Telescopes & Binoculars 25
Owl Services 83
Oxford University Press 61
Rainbow Symphony 82
Ritz Camera Superstores 85
Santa Barbara Instrument Group 89
Scope Buggy 84
Scope City 60
ScopeStuff 82
SCS Astro 83
Seymour Solar 83
Shutan Camera & Video 27
Sirius Observatories 82
Smartastronomy.com 85
Solarscope 82
Southeastern Camera & Telescope 82
Stargazers Inn 82
Starmaster Portable Telescope 82
Stellarvue 85
Surplus Shed 83
Technical Innovations 53
Tele Vue Optics, Inc 9
Telegizmos 83
The Teaching Company 13
Thousand Oaks Optical 82
University Optics, Inc 83
Vixen Optics 15
Wicked Lasers 77, 85
William Optics Co 53
Woodland Hills Camera & Telescopes 19
www.bigbinoculars.com 82

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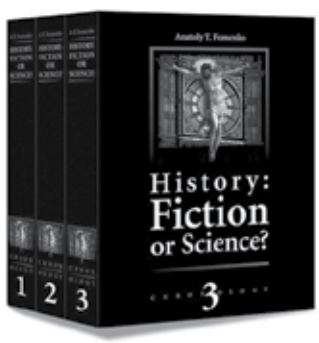

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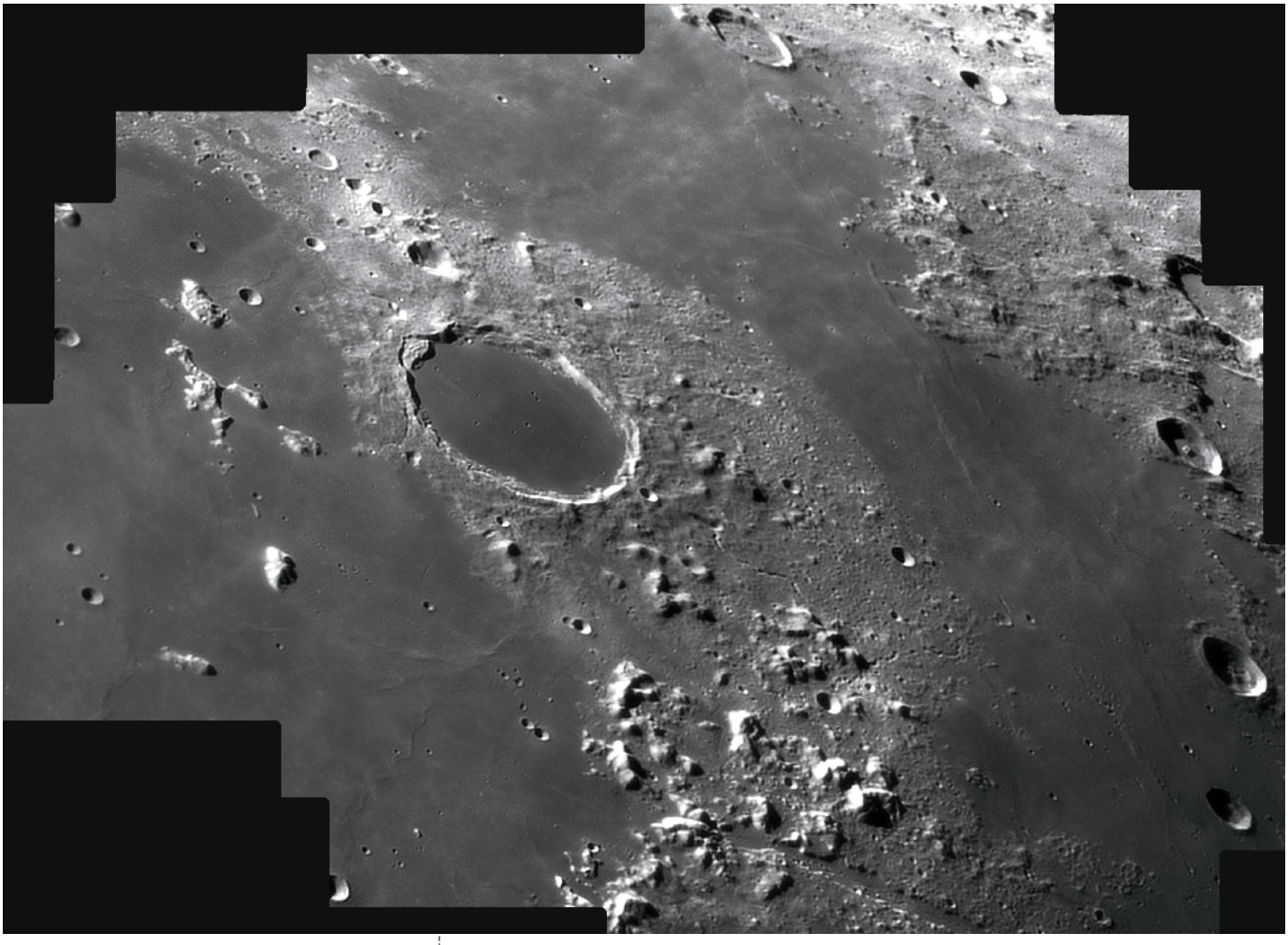

ALPINE VALLEY LANDSCAPE (10-inch Astro-Physics Maksutov-Cassegrain telescope at f/30, DMK 21BF04 CCD camera, twenty 0.0033-second monochrome images)
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A LUNAR PANORAMA

Plato and the Alpine Valley

Some of the Moon's most varied landscape lies at its top, as we view it. This panorama shows one crater — Plato — which measures 63 miles (101 km) across. The smooth region on the left of Plato is Mare Imbrium. Mare Frigoris is the river-like flat area that runs from lower-right to upper-left. The large, straight cleft at bottom is Valles Alpes, the Alpine Valley. Between it and Mare Imbrium lie Montes Alpes, the Moon's version of the Alps. The delicate crater at top center is 24-mile-wide (38 km) Fontenelle.

Send your images to: *ASTRONOMY* Reader gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of image and complete photo data: telescope, camera, and exposure information. To submit images electronically, visit www.contribute.kalmbach.com.

THE HERCULES CLUSTER (M13) ranks as the sky's eighth-brightest globular cluster. It shines at magnitude 5.8. (12-inch homemade Newtonian astrograph at f/4, SBIG STL 6303E CCD camera, LRGB image with exposures of 15, 10, 10, and 10 minutes, respectively) /// **BRIAN LULA, PRINCETON, MASSACHUSETTS**

THE BLUE FLASH (NGC 6905) is a planetary nebula in Delphinus near the borders of Vulpecula and Sagitta. (14-inch Celestron CGE 1400 Schmidt-Cassegrain telescope at f/5.4, Starlight Xpress MX-916 CCD camera, LRGB image with exposures of 40, 20, 15, and 25 minutes, respectively) /// **AL KELLY, FRIENDSWOOD, TEXAS**

COMET POJMANSKI (C/2006 A1) was a short-lived object seen in the morning sky during March 2006. It brightened enough that observers could find it through binoculars. (SBIG STL 6303E CCD camera, Nikon 400mm lens at f/2.8, LRGB image with 10 minutes total exposure time, taken March 8, 2006, at 4h00m UT) /// **PAOLO CANDY, SORIANO NEL CIMINO, ITALY**

SHARPLESS 2–171 in Cepheus measures nearly 3° across. Although it images well, Sh 2–171 is difficult to see visually. (6.4-inch Takahashi Epsilon-160 astrograph at f/3.3, SBIG STL 6303E, HαRGB image with exposures of 150, 25, 25, and 25 minutes, respectively) /// **DEAN SALMAN, TUCSON, ARIZONA**

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This incredible two frame mosaic of NGC 2170 was taken by Russ Croman with an SBIG STL-11000M camera through a 20" f/8 RC scope. The total exposure time was 16 hours per frame. Selected as NASA's Astrophoto of the Day, February 28, 2007.

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